ELECTRICAL INSULATION

Its Application to Shipboard Electrical Equipment

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In its search for new and improved electrical insulation the Bureau of Ships has promoted the use of high-temperature silicone insulation. These promotional efforts have been realized in material and equipment contracts with industrial concerns for complete test analysis of the insulation. These test data have been used to integrate design and application requirements for high-temperature insulation in new-ship construction programs as well as maintenance and repair of presently installed equipment.

As there is no previously published information that contains all the whys and wherefores of electrical insulation under one cover, it is believed that this book will cover a long-felt need in this important field.

This book should be put into the hands of personnel directly concerned with electrical insulation for ready reference and study. Any comments or suggestions that may improve this book will be welcome.

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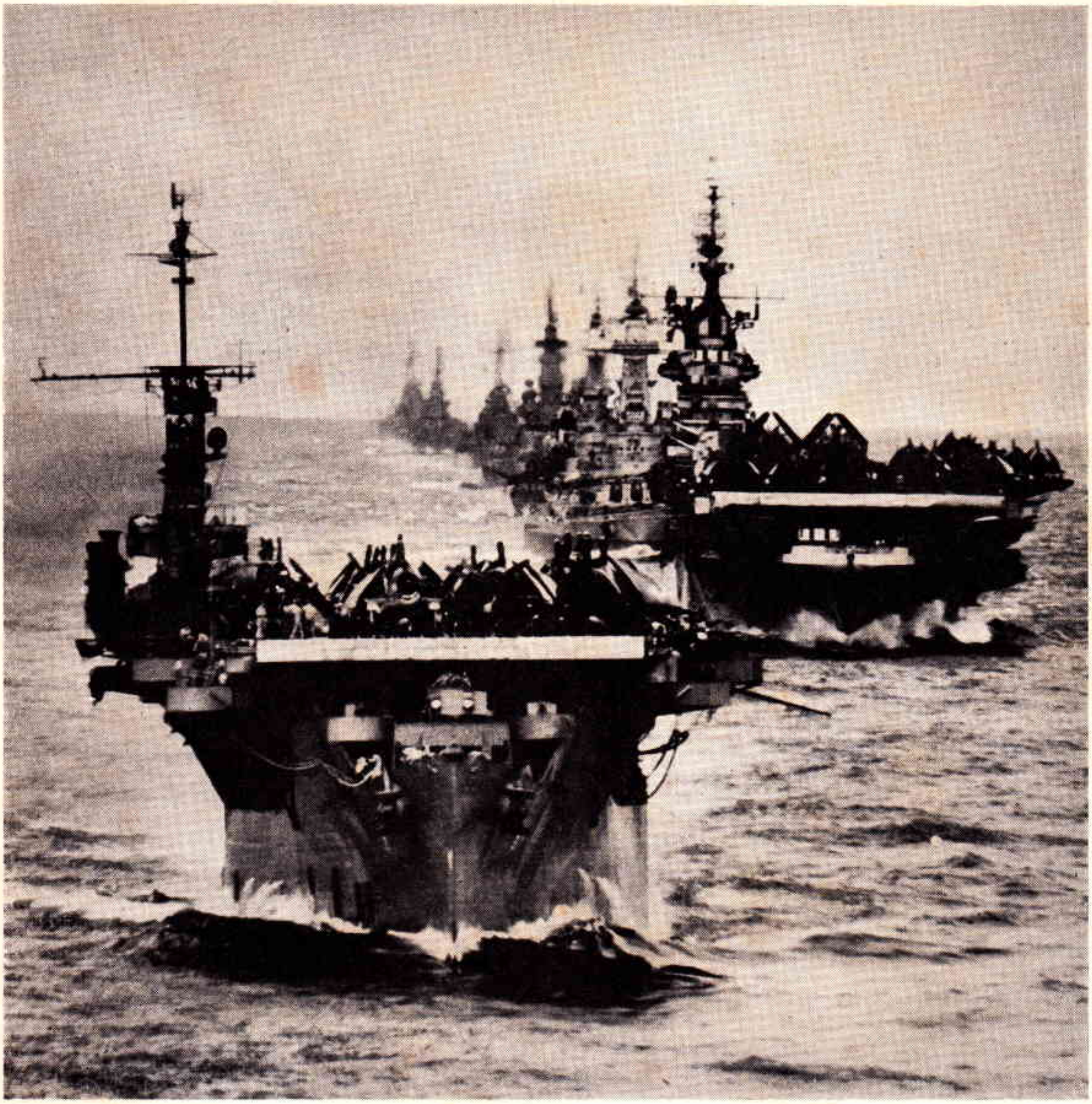

ELECTRICAL INSULATION

Its Application to Shipboard Electrical Equipment

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FIRST EDITION

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Preface

This manual has been prepared with two objectives in mind: (1) to make available under one cover the latest information on electrical insulating methods and materials, (2) to acquaint Navy personnel with the high-temperature silicone (class H) insulation which is now finding its place in the fleet in electrical equipment where moisture and temperature conditions have previously caused high maintenance costs when conventional materials were used.

The trends in design of electrical equipment today for shipboard use are toward higher temperatures; increased reliability; smaller, lighter weight equipment; and elimination of cellulose-base materials to reduce fire and toxic hazards.

As the insulation is the heart of the electrical plant, it cannot be overstressed that the best obtainable materials and the most reliable methods of application should be utilized to ensure continued operation with a minimum of maintenance.

Although this manual has been prepared on the basis of primarily covering rotating electrical equipment, the materials and methods of application are applicable in most cases to all types of electrical equipment.

This manual necessarily includes much information supplied by the U.S. Navy as well as by many industrial organizations and individuals. It has been the objective of the author to blend this diversified information with other technical information so as to present a clear, concise yet comprehensive picture of the art of applying insulation to electric machinery. Contributions, help, and comments of the following companies are gratefully acknowledged:

Allis-Chalmers Manufacturing Company
Anaconda Wire and Cable Company
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Elliott Company
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National Electric Coil Company
National Vulcanized Fibre Company
Owens-Corning Fiberglas Corporation
The Acme Wire Company
The Formica Insulation Company
The National Varnished Products Corporation
The Okonite Company
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Varflex Corporation
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In addition to the technical information and help furnished by representatives of these contributing companies, individual engineers have spent a great deal of time in review of the manuscript and guidance of the author in its preparation.

The assistance and helpful suggestions of H. P. Walker of the U.S. Navy Department, Bureau of Ships, Electrical Branch, have been of inestimable value. The splendid cooperation of A. J. Sherburne of the General Electric Company, T. A. Kauppi of the Dow Corning Corporation, and G. P. Gibson and many other associates of the Westinghouse Electric Corporation is acknowledged with deep appreciation.

Illustrations were offered by many of the contributing organizations. Those used are credited individually.

GRAHAM LEE MOSES

PITTSBURGH, PA.
February, 1951

Contents

ELECTRICAL INSULATION

Its Application to Shipboard Electrical Equipment

1. Insulation Theory and Basic Concepts

Insulation is the weakest link in the chain which harnesses electricity as man's servant. Yet it is absolutely essential to every electrical device. All insulation has limitations and weaknesses, as no one material possesses all the desired properties and most materials have bad as well as good characteristics. The situation is so complex as to be confusing unless it is carefully studied from the point of view of the objectives of applying insulation with a frank acknowledgment of the material limitations. The early development and application of insulation were based almost entirely on the cut-and-try approach. Even the application of insulation in the factory and repair shop was considered an "art" rather than a practical science.

In recent years much progress has been made through a scientific approach to insulation evaluation and development. This has led to a better understanding of the phenomena encountered with a more logical approach to insulation design and manufacturing problems. Inevitably this approach will lead to better and more economical machines, even those employing the presently available materials. Furthermore, it will accelerate the development of better insulating materials that may overcome the inherent limitations of existing insulations.

It is the purpose of this manual to present a practical view of insulation problems encountered in rotating electric machines, **especially those for shipboard use.** Emphasis will be placed on why certain practices are followed rather than precisely how. American engineers, technicians, and workmen have adequate native ingenuity to devise ways to do a job once they understand the basic underlying principles. The manual will avoid purely theoretical discussions but will include sufficient theoretical background so that practical problems and experiences can be explained and understood by the reader. A sound background of basic concepts is essential for a clear understanding of insulation problems and phenomena. These basic concepts are presented in simple, understandable language with only the essential mathematics in elementary form. All the theory and basic concept statements included in this manual have a practical significance.

1-1. PLAN OF MANUAL

The manual has been planned to have the fundamental and theoretical information as the introduction. This has been kept simple and direct. However, it does introduce a few new points of view which aid in understanding later chapters. It is therefore recommended that even those thoroughly familiar with insulation fundamentals review this introduction.

Next, classes of insulation and their properties are discussed at length. Their temperature classification is reviewed. Typical varieties of each kind are described and evaluated for the purpose of creating sound basic concepts of insulation practices. **Considerable emphasis is given class H insulations and their use.** The general function of insulating materials and their selection are discussed on the basis of the physical properties, the electrical properties, and the chemical properties of materials.

Then general coil construction is reviewed thoroughly. Important varieties of coils used in electrical apparatus are described. This includes both random-wound construction and form-wound construction of coils. Material selections are discussed at length, and the basis for choices reviewed. Commutator construction is described. The types of materials used are reviewed, and the several philosophies of commutator design and building discussed.

Motors and generators are classified according to their basic construction and application requirements. The problems involved in winding and insulating are discussed in detail, including such factors as:

1. Removal of old insulation.
2. Cleaning.
3. Separate parts of winding insulation.
4. Wiring around frame.
5. Putties or cements.

A separate chapter is devoted to varnish treatment and allied processing subjects. This includes special processing and storage problems encountered in high-humidity atmospheres as well as protection against termites, bacteria, and fungi. This part also includes cleaning and drying old windings, which is an essential preliminary to re-treating them with varnish.

The philosophy of testing electrical apparatus is reviewed, and the limitations involved discussed. Tests are classified according to their purpose, and the general objectives discussed in considerable detail. Industry standards are reviewed, and maintenance tests described. The testing of turn insulation is separated from the testing of ground insulation, and the various methods of such testing described in detail. Suggestions are given as to how overpotential tests can be made in the absence of conventional test apparatus.

One chapter is devoted to maintenance programs. It describes various maintenance procedures and suggests inspections and maintenance periods.

The final chapter is a summary of the outstanding points covered by the main text. The information is arranged so as to form a ready reference under a wide variety of headings as to things which should be done as well as practices to be avoided in order to maintain apparatus in operable condition.

1-2. INSULATORS

Insulators are conductors of such high resistivity that the flow of current through them can usually be neglected. The dividing line between conductors and good insulators is so indefinite that they are usually separated by another group of materials which might be called semiconductors. These three groups, listed according to arbi-

trary limits of volume resistivity, are as follows:

Group	*Volume Resistivity, Ohm-cm*
Conductors	10^{-6}–10^{0}
Semiconductors	10^{0} –10^{6}
Good insulators	10^{6} –10^{20}

1-3. INSULATION RESISTANCE

All solid insulations conduct electricity to some extent and can therefore be said to have insulation resistance. The insulation resistance is defined as the resistance offered by insulation to direct voltage which tends to produce a leakage current through the insulation and over its creepage surfaces. The resistance of an insulation is not necessarily a measure of its dielectric strength but, when properly interpreted, may afford a useful indication of whether the insulation is suitable for operation or preventive maintenance is required. Insulation-resistance tests are commonly made to check insulation condition. A high value of insulation resistance usually indicates a clean, well-dried insulation **but does not prove that the insulation is free from mechanical faults which might cause dielectric breakdown.** Unusually low insulation resistance or sudden changes indicate contamination and should be investigated. Insulation-resistance tests are commonly made with 500 volts dc and may be considered nondestructive.

This property of insulation is subject to wide variation with temperature as well as differences in humidity and moisture content of the insulation. **Cleanliness of the creepage surfaces is also an important factor.** Furthermore, insulation resistance will vary with the value of the applied test voltage and the time of the application of the voltage. Many of the apparent inconsistencies of insulation-resistance data can be explained if these factors are properly evaluated. It is important that, where successive or periodic measurements are to be correlated, the tests be made with a definite voltage for a specific time and with correction made for temperature.

The measured value of insulation resistance will increase with the time that the voltage is applied, changing rapidly at first and later less rapidly, with the readings gradually approaching a stable value. Values at 30 seconds may be as low as 10 percent of the final values. The insulation resistance of clean, dry insulation may continue to increase for hours with continuous voltage application. However, an approximately steady value will generally be reached in 10 to 15 minutes. In wet or dirty insulation the steady value of insulation resistance is usually reached quickly. This change in apparent insulation resistance is a dielectric absorption phenomenon (see Sec. 1-6). It is dependent upon the character and condition of the insulating material rather than size or voltage rating of the equipment.

Insulation-resistance tests are usually made at d-c voltages from 500 to 5,000 volts, although more recently some insulation-resistance tests have been made as high as 15,000 volts (on windings of high-voltage machines). Insulation resistance decreases somewhat with an increase in applied voltage. In most cases there is no significant difference in insulation resistance observed in the range of 500 to 1,000 volts. Any marked variations in insulation resistance due to voltage in this range may be caused by moisture.

Insulation resistance varies inversely with the temperature at a rate depending upon the type of insulation, the degree of moisture present, and the condition of the insulation surface. Experimental work has indicated

that the effect of temperature can be approximated by the following formula:

$$R_{t2} = R_{t1}C^n$$

where R_{t2} = insulation resistance to be estimated at t_2 temperature.
R_{t1} = insulation resistance at known temperature t_1.
n = exponent equal to 0.1 $(t_1 - t_2)$.
C = constant for the type of insulation (see Chap. 6).

For a comprehensive discussion on insulation-resistance testing refer to Chap. 6.

1-4. INSULATION RESISTIVITY

The resistance per unit volume of insulation is known as the resistivity. This is usually expressed in megohms per inch cube, which is commonly referred to as "megohm-inches." The resistivity of insulations is not a constant, as it varies widely depending on many factors. The concept of insulation resistivity is useful in establishing base values of insulation resistance from which variations may be interpreted.

Typical resistivities of insulation systems employing mica in tape or wrapper forms are tabulated below for clean, dry, new windings.

If the slot area of a winding and the thickness of the insulation wall are known, the approximate insulation resistance (does not include surface leakage) may be calculated as follows:

$$R_i = \frac{r \times t}{a}$$

where R_i = insulation resistance of the winding at 25 C.
r = specific resistivity of particular insulation (from table above).
t = thickness of insulation wall, inches.
a = area contact of insulation and iron in all slots of winding, square inches.

1-5. DIELECTRIC ABSORPTION

Dielectric absorption is that property of an imperfect dielectric which results in an accumulation of electric charges within the body of the material when it is subjected to an electric field. When a dielectric is charged, this condition is manifested by a decrease in current with time until the steady-state conduction current is reached. On discharge it results in a current which may flow for a long time with decreasing magnitude until the dielectric is fully discharged.

Where a d-c voltage is applied to any insulation system, between two electrodes, there is an initial rush of charging current

Type of machine	Insulation class	Resistivity at 25 C, megohm-in.*	
		Average	Range
Large a-c low-voltage	A	60×10^6	20–140 ($\times 10^6$)
Large a-c low-voltage	B	135×10^6	40–250 ($\times 10^6$)
Large a-c high-voltage	B	150×10^6	30–350 ($\times 10^6$)
Large d-c medium-voltage	B	70×10^6	10–150 ($\times 10^6$)

* Megohm-inch is the unit of resistivity which is equal to the megohms measured between parallel faces of a 1-inch cube of the composite insulating structure.

which is the equivalent of the current charging a condenser. If the insulation between the electrodes were a perfect dielectric, having no conductivity, current flow would cease when the condenser was charged. However, practically all insulation has finite resistance and the charging current is increased by the amount of the current which is conducted through the insulation. There is a third current component which provides energy for rearranging the molecular structure of certain insulations. Therefore, there are three definite current components which, taken together, represent the total current flow through the system. Since these vary in their magnitude and timing, it can be seen that the current "absorbed" by an insulation system will vary with the time of voltage application. The phenomenon of this varying current is known as "absorption." (This is of interest in insulation-resistance testing.)

1-6. DIELECTRIC CONSTANT

The nature of the insulation between electrodes determines its dielectric constant (K) or specific inductive capacity (SIC). This dielectric constant is the ratio of the capacitance of a capacitor containing a particular dielectric material to the capacitance of the same capacitor with air as the dielectric medium. The dielectric constant is of interest as it affects the voltage distribution across two or more insulations in series (which will be discussed later).

The dielectric constant is also defined as that property of a material which determines the electrostatic energy stored in the material (per unit volume per unit potential gradient).

Following are the dielectric constants of a few insulating materials. In most cases materials have a range rather than an absolute and invariable value.

Material	*Dielectric Constant*
Asphalt	2.7
Bakelite	4.5–5.5
Fibre	2.5–5
Glass	5.4–9.9
Mica	2.5–6.6
Paper	2.0–2.6
Pressboard	3–5
Rubber	2–3.5
Shellac	2.9–3.7
Water	81

1-7. POWER FACTOR

The power factor of an insulation system is a measure of the relative dielectric loss in the insulation. It is the ratio of the energy loss in watts to the volt-ampere input to the dielectric system considered as a condenser. Mathematically this is expressed as being the cosine of the dielectric phase angle (or the sine of the loss angle). Power factor is of interest in that it is nondimensional and is a relative measure of insulation quality. On the other hand it generally does not detect weak spots and is more or less an average value for the insulation system under observation. It is of little practical significance in insulation for machines operating at less than 8,000 volts.

1-8. DIELECTRIC LOSS

Dielectric loss is the time rate at which electric energy is transformed into heat in a dielectric when it is subjected to a changing electric field (ASA). The principal sources of energy loss in a dielectric are absorption and leakage, the former being the more important of the two in most insulating materials. Both are greatly affected by moisture and temperature. The measure of their combined effect, with alternating voltages, is usually expressed in terms of the power factor and loss factor. Dielectric loss factor of a material is the

product of its dielectric constant and the dissipation factor.

1–9. DISSIPATION FACTOR

Dielectric dissipation factor (D) is the tangent of the dielectric loss angle ($\tan \delta$). It is also the ratio of equivalent series resistance to equivalent series capacitive reactance.

1–10. DIELECTRIC STRENGTH

When an insulator is subjected to a voltage which will produce rupture, the voltage at which breakdown occurs is said to be the dielectric breakdown strength. Dielectric strength will depend on a number of factors such as the rate of voltage rise, duration of voltage application, frequency of the voltage, temperature, atmospheric conditions, thickness of the specimen, and the electrode configuration. It is therefore necessary that these conditions be standardized. ASTM standards (see Chap. 6) define the size of electrodes, rate of rise of voltage, frequency, and duration of voltage stress under certain conditions. There are two recognized standards of such dielectric breakdown tests. One is the rapid-rise short-time test, and the other is the step-by-step test, where each successive voltage is held for a specific length of time (usually 1 minute).

1–11. AIR BREAKDOWN

When the voltage on a pair of electrodes immersed in a gas, such as air, is raised to a high enough value, a luminous discharge occurs. In air at atmospheric pressure, this discharge usually takes the form of a bright flash accompanied by a sharp, cracking, explosive noise. This is known as spark-over or gaseous breakdown. Just preceding the spark-over there is a small, dark discharge current through the gas (corona). Upon the application of sufficient voltage free electrons in the field move toward the anode and multiply by collision. The rapidly increasing electrons force their way through the gas, producing sufficient heat to cause thermal ionization, and a streamer is formed. One end of the streamer becomes attached to the adjacent electrode, and the other develops at an increasing rate until the gap is spanned. When this develops, the gap may be said to be broken down, as it conducts current, and the voltage across it collapses.

The breakdown of air under voltage stress in a uniform field is quite reproducible. It has therefore been selected as

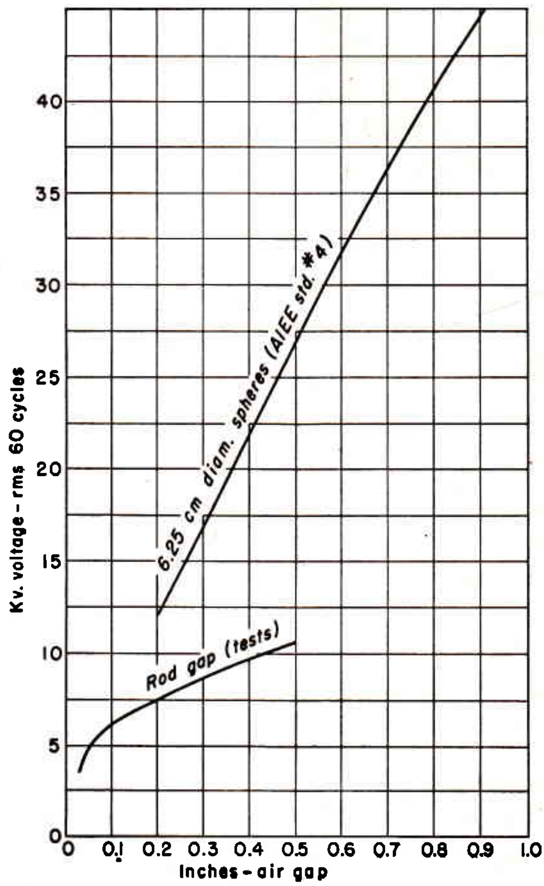

FIG. 1–1. Air breakdown between sphere gaps and rod gaps.

FIG. 1-2. AIR-DENSITY CORRECTION FACTORS FOR SPHERE GAPS

(Based on standard conditions of 25 C and 760 millimeters barometric pressure)

Relative air density	Diameter of standard spheres, cm				
	6.25	12.5	25	50	75
0.50	0.547	0.535	0.527	0.519	0.517
0.55	0.595	0.583	0.575	0.567	0.565
0.60	0.640	0.630	0.623	0.615	0.613
0.65	0.686	0.677	0.670	0.663	0.661
0.70	0.732	0.724	0.718	0.711	0.709
0.75	0.777	0.771	0.766	0.759	0.757
0.80	0.821	0.816	0.812	0.807	0.805
0.85	0.866	0.862	0.859	0.855	0.854
0.90	0.910	0.908	0.906	0.904	0.903
0.95	0.956	0.955	0.954	0.952	0.951
1.00	1.000	1.000	1.000	1.000	1.000
1.05	1.044	1.045	1.046	1.048	1.049
1.10	1.090	1.092	1.094	1.096	1.097

a standard for measurement of higher voltages by the AIEE. AIEE Standard No. 4 (ASA, C68.1) describes these test procedures in complete detail. Figure 1-1 shows the relation between sphere gap spacing in inches and the 60-cycle breakdown voltage. In using these data it is necessary to determine the "relative air density." In the following formula:

$$\text{RAD} = \frac{0.392b}{273 + t}$$

where b = barometric pressure, millimeters of mercury.

t = temperature, degrees C.

The correction factors for breakdown are approximately equal to the relative air density. For absolute values refer to Fig. 1-2.

An interesting and significant factor of air breakdown is that the curve which appears to be headed toward zero voltage does not actually approach zero, at the lower separations, until positive contact occurs. At very low gap spacing in air the breakdown voltage actually increases as shown in Fig. 1-3. This is based on Paschen's law. **Under this law there is a minimum voltage which will break down air which is equal to 335 volts dc (or the peak of an a-c wave).** This is a very significant fact which will be discussed further later in the text.

1-12. BARRIER EFFECT OF SOLID INSULATION

Solid insulation provides far greater dielectric protection than air spacing because of the barrier effect. However, the barrier must be effectively solid, and not porous; otherwise the insulation may have an even lower dielectric breakdown than air. In general solid insulation must be formed by built-up layers of mica, varnish, or other individually treated laminae, although liquid-impregnated porous insulation may be an adequate barrier. The technique of fabrication is very important

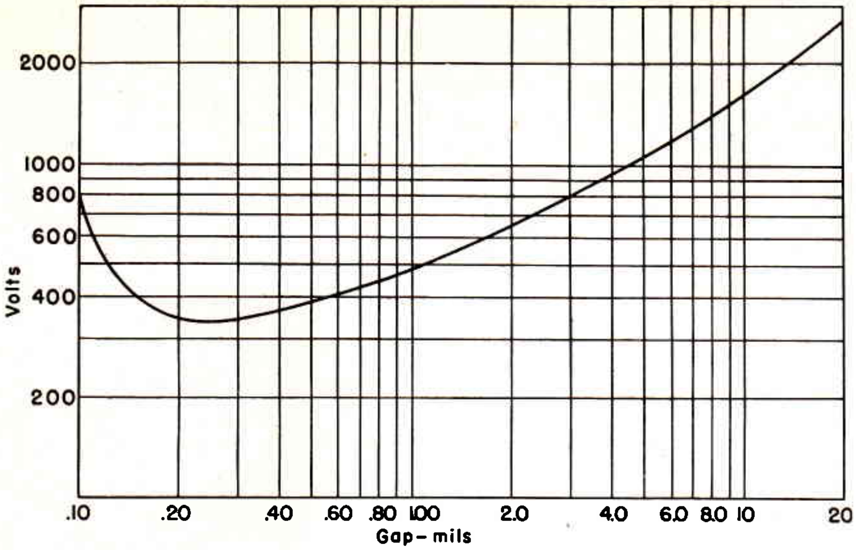

FIG. 1-3. Breakdown of air at small spacings from Paschen's law.

in the production of a solid barrier, and it is quite difficult sometimes to tell by inspection whether a piece of material is an effective dielectric barrier or not. Two seemingly identical materials may have dielectric breakdown strengths differing by a factor of 10, depending upon the manner in which they were made.

1-13. THEORIES OF DIELECTRIC BREAKDOWN OF SOLID INSULATION

1. *Thermal Theory.* The thermal theory of breakdown (suggested by Wagner) is based on the assumption that all solid dielectrics are heterogeneous and that some spots, layers, or filaments of a dielectric have lower resistance than other apparently similar parts. By this theory the current distribution over a given insulation sample is not uniform. The weak part carries more current and is heated more than other parts. As long as the insulation or the adjacent electrodes can conduct the heat away as fast as it is generated, the temperature will remain stable and no failure will occur. However, if the heat is not removed so rapidly as it is generated in the dielectric, the weaker spots grow hotter and their resistance becomes lower (most insulations decrease in resistance as their temperature increases). This temperature rise continues

Thickness	Material	Dielectric breakdown, volts, 60 cycles, 1 min	Spacing breakdown voltage, 60 cycles	Ratio of solid breakdown to air-spacing breakdown
0.001	Mica flake	4,000	400	10.0
0.010	Treated cloth	7,300	1,070	6.83
0.012	Fish paper and mica	6,000	1,225	4.9
0.015	Fish paper	6,000	1,425	4.2

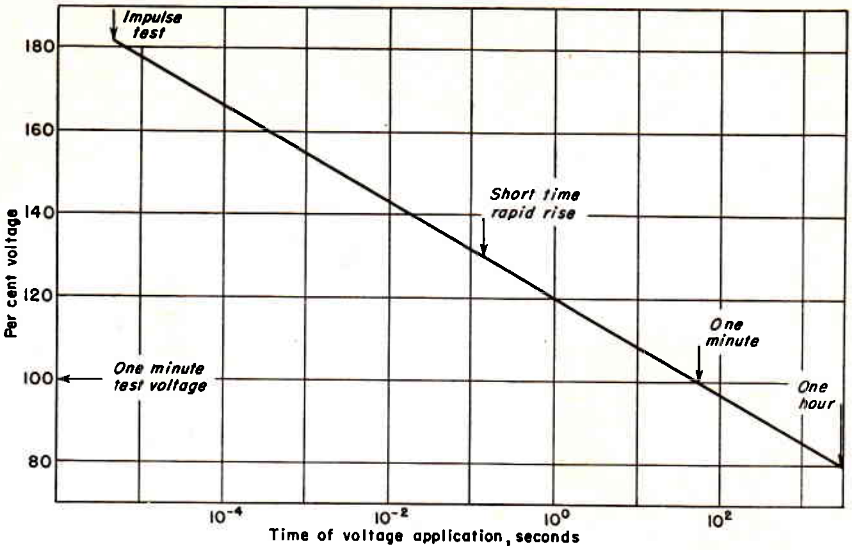

FIG. 1–4. Time-voltage breakdown relationship of an asphalt-bonded mica insulation.

until thermal instability occurs followed by breakdown of the insulation.

2. *Ionic Theory.* This theory is based on the premise that a solid dielectric acts as an electrolyte in which ions move to produce current flow. This ionization may be from collision or chemical action under the influence of the field voltage. In both cases as the voltage is increased, the fast-moving ions will dissipate energy and produce other ions. As the higher intensity field is produced by increasing voltage, ions are produced at an ever-increasing rate until instability occurs and insulation failure results.

3. *Disruptive Theory.* Under this theory electric breakdown of insulation is considered to be a physical rupture with the destruction of molecular and other bonds in the dielectric. There is considerable evidence to support this theory, as it is known that the breakdown of thin specimens and insulation at low temperatures are not explained by thermal or ionic theories. For example, surge breakdowns which may occur in the order of 1 microsecond can best be explained by this theory.

1–14. EFFECT OF TIME

It is well known that solid insulation will break down at different voltages depending upon the time of voltage application. Therefore, in defining any dielectric breakdown-strength data it is absolutely essential that the time of voltage application be specified. This is, of course, normally done by referring to the ASTM test standards which give time values for various types of tests.

Recently tests were made on a mica insulation ranging from voltage application times of a few microseconds up to a million seconds. This investigation showed a very interesting relation between voltage and time to breakdown on a logarithmic scale. This is shown in Fig. 1–4. For example, if the 1-minute breakdown voltage is considered 100 percent, then short-time rapid-rise breakdown voltage was found to be equal to 130 percent and the impulse breakdown equal to 180 percent. Going in the other direction, the voltage required to break down this insulation after 1-hour

voltage application was only 80 percent of the 1-minute value. The following is an interesting formula offered by Montsinger for the relation between breakdown voltage and time:

$$KV = K\left(a + \frac{1-a}{\sqrt[4]{T}}\right)$$

where KV = breakdown voltage at T time.
T = time, minutes.
K = 1-minute strength.
a = constant of the material depending upon temperature, frequency, etc.

Figure 1–5 shows how this formula applies to certain forms of insulation.

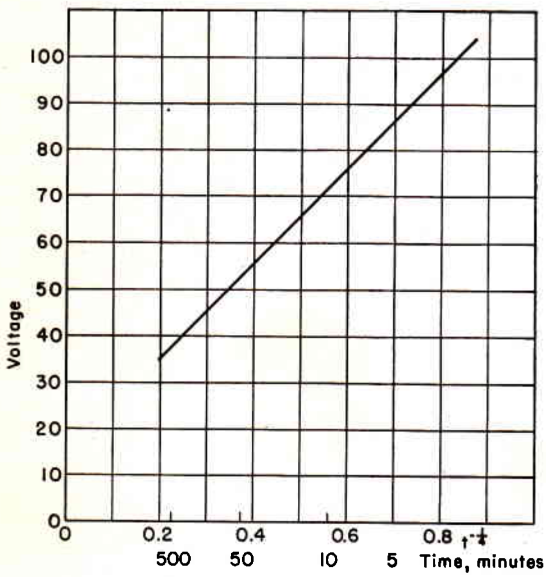

Fig. 1–5. Time-voltage relationship from formula (Sec. 1–14).

1–15. EFFECT OF VOLTAGE SOURCE

The effect of a-c and d-c voltages on insulation must be differentiated. With ac there is a dielectric loss within the insulation, so that in general a lower a-c voltage is required to break down a solid insulation than a d-c voltage. (This follows from the thermal theory of breakdown.) In addition it must be recognized that a-c voltages are in terms of rms values whereas the peak for a sine wave will be equal to 141 percent of the rms value. Thus it will be found that the d-c breakdown voltage of solid insulation is nearly always more than 150 percent of the a-c rms voltage. In some cases it will be found to be 250 percent or more depending on the nature of the material. Since no practical relationship exists between a-c and d-c breakdown of solid insulations, it is customary to use ac for all conventional destructive tests or proof tests. (High-voltage d-c testing is experimental as a maintenance procedure.)

1–16. SPACING INSULATION

In many forms of electrical apparatus it is not necessary to provide positive dielectric barrier action. Spacing through porous insulation may be entirely adequate for many applications. Generally the value of spacing as insulation is approximately equal to the air breakdown at that spacing. For example, refer to Fig. 1–6. **It will be found that 0.005-inch spacing through air is equal to a breakdown strength of approximately 1,000 volts. This is essentially true whether it is through air or through dry porous insulation such as cotton or fibrous glass.** Humidity may reduce the breakdown through porous insulation.

1–17. VOLTAGE DISTRIBUTION ON DISSIMILAR MATERIALS

When two different insulating materials are in series, it is not correct to add the known dielectric strengths of the two insulating materials. The voltage distribution will depend upon the dielectric constants, K_1 and K_2, of the two materials. The relations among voltage gradients, di-

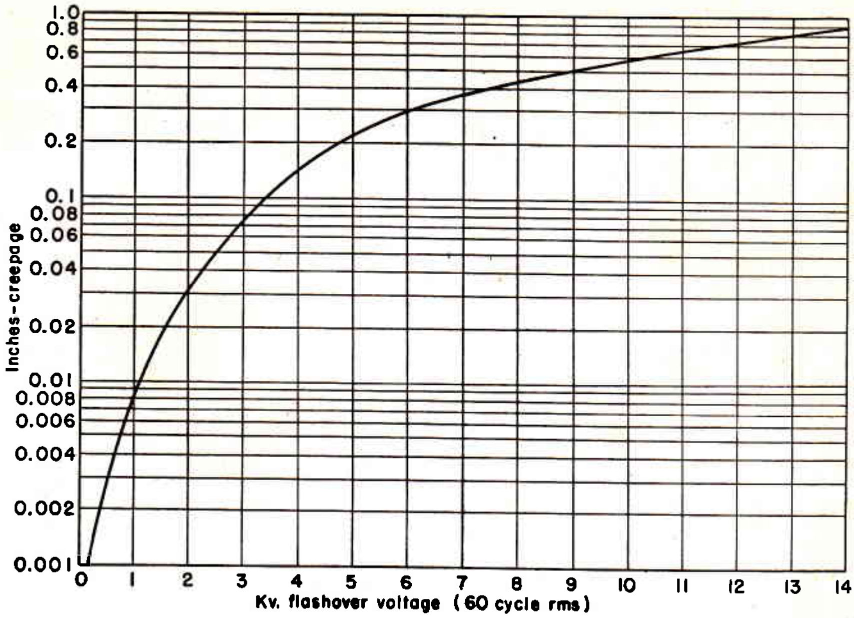

FIG. 1–6. Spacing breakdown or creepage flashover voltage through porous insulations or over short creepage surfaces.

electric constants, thicknesses, and total applied voltage are given by the following equations:

$$\frac{E_1}{E_2} = \frac{K_2}{K_1}$$

$$E_1 = \frac{K_2 V}{d_1 K_2 + d_2 K_1}$$

$$E_2 = \frac{K_1 V}{d_1 K_2 + d_2 K_1}$$

where E_1 = voltage gradient in insulation 1, volts per mil.
E_2 = voltage gradient in insulation 2, volts per mil.
K_1 = dielectric constant of insulation 1.
K_2 = dielectric constant of insulation 2.
d_1 = thickness of insulation 1.
d_2 = thickness of insulation 2.
V = total voltage applied across the two insulating materials in series.

1–18. VARIABILITY AND STATISTICAL ANALYSIS METHODS

In the study of insulation it is important to recognize that the characteristics of insulation are widely variable. When data are reported on almost any characteristic of insulation that can be mentioned, the individual observations will necessarily be dispersed within a relatively broad band. It is customary to indicate the average value; however, in addition it is necessary to have some knowledge of the degree of variation that can be expected on either side of the average. Statistical analysis methods and probability theory are coming into widespread use in interpreting insulation phenomena. It is therefore desirable that all persons dealing with insulation have a brief knowledge of these principles.

A fundamental concept essential to the understanding of statistical analysis methods is **that there is such a thing as variation.** Many persons visualize a number as an

exact evaluation or measure of something. This idea originates in the process of counting, wherein bank balances or quantities of material are exactly expressed by a cardinal number. On the other hand, engineers, and especially insulation engineers, are more concerned with the process of measuring characteristics. A measurement is a scientific estimate of a quantity and hence is subject to variation. All measurements are necessarily subject to some variation, and a means of expressing the degree of variability is a primary need.

Insulation engineers are interested in measurement of physical and electrical properties of available materials and structures. Insulation practices are necessarily based on the background of experience with these materials. It is therefore of the utmost importance to obtain reliable data and to be able to predict the reasonable limits of variability for a given product.

Only two basic concepts are needed for understanding of this method of presenting data, namely:

1. There is a central tendency of observed data which is expressed as the average of observed values.

2. Most individual data differ from the average but distribute themselves about the average in a regular pattern. The amount by which such data vary from the average is measured by the "standard deviation."

Everyone is familiar with the arithmetic average (or mean), and no further discussion is needed. Individual data are usually identified as X_1, X_2, X_3, etc., and their average as $\overline{X}$.

The "standard deviation" (usually identified as the Greek letter sigma—σ) is a measure of the randomness or dispersion of data. It is the root mean square of the individual deviations from the average ($\overline{X}$). In other words, the individual deviations from the mean are squared; the squares are added and the sum divided by the number of observations to give the mean square of the deviations; then the square root of this mean square is extracted. The standard deviation is always in the same units as the average.

It is sometimes desirable to express this variability or dispersion in relative terms. For this purpose, the "coefficient of dispersion" (S) is used. This is the ratio of standard deviation to the average expressed as a percentage.

The term "range" (R) is applied to the area lying between the lower limit of 3σ below the average and the upper limit of 3σ above the average, as only 0.26 percent of all observations will lie outside this range (0.13 percent below and 0.13 percent above).

The theory of probability is a useful tool in statistical analysis methods, as it aids in analyzing data with speed and reasonable reliability. It permits calculating deviation from average values and predicting probable error. This greatly aids in making an intelligent analysis or prediction and minimizes errors in judgment. The error of drawing conclusions from a single test has frequently been demonstrated because of the great probable variation in individual tests. On the other hand, it is well known that, when a sufficient number of units is tested or measured, the results will cluster around a theoretical average for an infinite number of samples in a normal manner. The existence of normal distribution of such observations is well established by practical observations and mathematical calculations.

The manner in which individual observations tend to cluster around the average and deviate from it in a normal distribu-

tion is illustrated in Fig. 1-7. This indicates that within $\pm 1\sigma$ (one standard deviation) of the mean will lie 68.26 percent of all the observed values (± 34.13 percent from the mean). Similarly, within $\pm 2\sigma$ will lie 95.44 percent of all observations (± 47.72 percent from the mean). Also the "range" ($\pm 3\sigma$ from the mean or average value) will contain practically all the observations. (Only 0.13 percent of the group lie outside this range at either end of the scale.)

Probability paper is a very useful tool for analyzing data graphically without lengthy calculations. It is designed so that data with normal distribution plot a straight line. This paper is available with both arithmetic and logarithmic ordinates. An example of its use is shown in Fig. 1-8.

One of the most important precautions that must be followed in taking data for statistical analysis is the selection of random samples. In order that the tests be reliable and significant of the whole problem, it is essential that a random sample be obtained which is truly representative of the whole. No bias of any kind must enter into the choice of samples to be tested.

Once the concept of statistical analysis is clear, it greatly simplifies visualizing relative characteristics of insulation whether they are physical size, mechanical strength, or dielectric properties. A few simple figures can describe a vast mass of data which, unanalyzed, may be confusing. Knowledge of the central tendency is important, but a measure of the dispersion also is essential. It is desirable to know whether the individual values are grouped closely about the mean or widely scattered and dispersed. This is particularly important in insulation work in predicting the probability of values falling within a given range. Average alone is misleading.

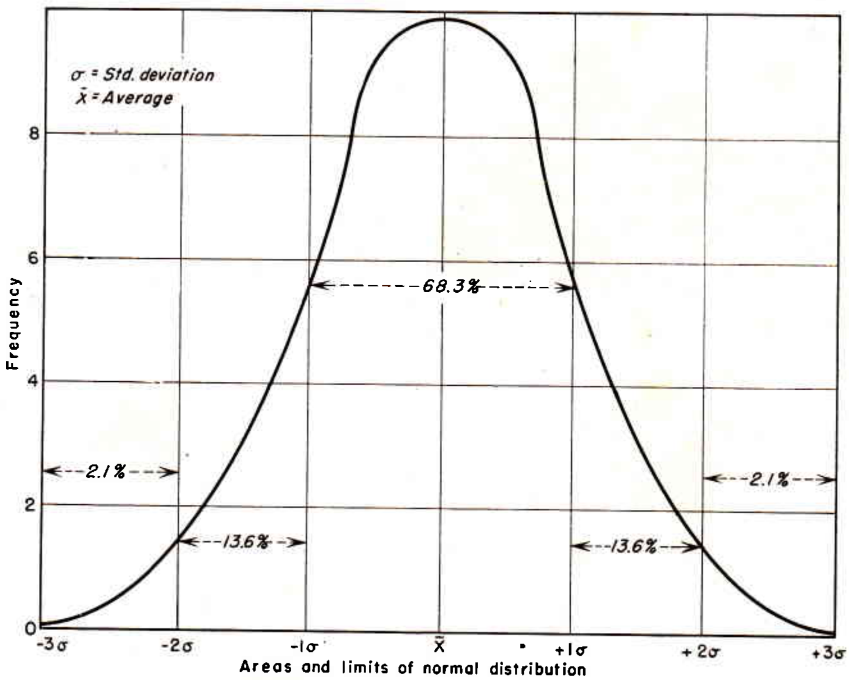

Fig. 1-7. Normal frequency-distribution curve.

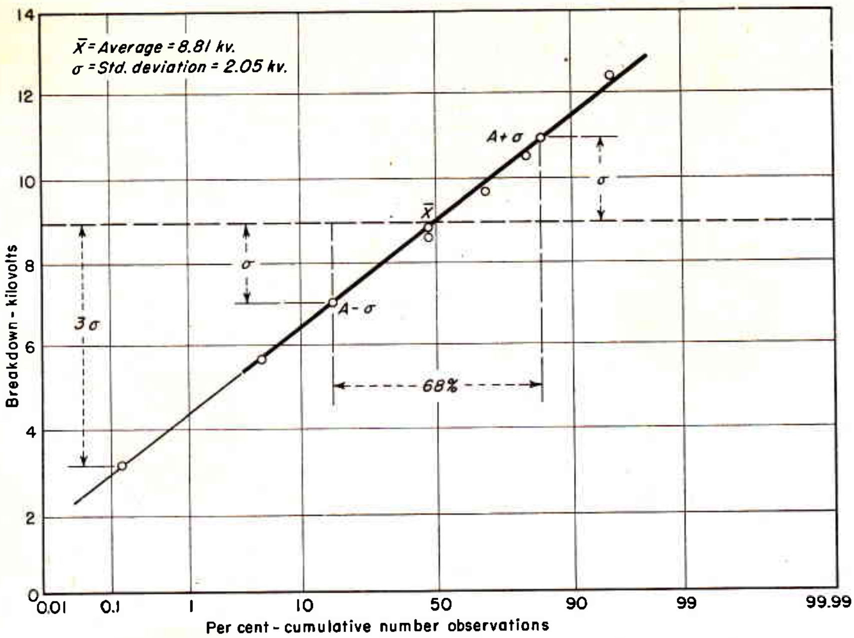

FIG. 1-8. Curve of dielectric breakdown voltage as a function of cumulative probability of failure on mica insulation.

The basic factors involved in such statistical analyses are:

Average or arithmetic mean	$\bar{X}$
Standard deviation	σ
Coefficient of dispersion (%)	S
Number of samples observed	N
Range ($\pm 3\sigma$ from the average)	R

It must be remembered that such statistical methods are merely tools and guides to aid in the exercise of judgment. They provide standardized and simplified methods of examining and analyzing data. They may make some factors more evident and give a better perspective of a complex situation but cannot replace sound engineering judgment.

1-19. THERMAL AGING OF ELECTRICAL INSULATION

Engineers have long recognized that a relationship exists between the life of electrical windings and the operating temperature of the insulation. This is a complex relationship which has required a great deal of study before engineers could draw rational conclusions on the subject and hazard predictions as to probable life of various types of insulation. **It has been found that insulation does not fail by immediately breaking down when reaching any critical temperature.** It fails by a gradual mechanical deterioration with time at elevated temperature. Thus the question of "how hot an insulation may be permitted to operate" can be decided only on the basis of "how long it is desired to have it last." The time-temperature relation is what determines the rate at which the mechanical strength of organic material decreases. As these organic materials become more brittle and less strong, they disintegrate under the influence of vibration, shock, differential expansion, and other mechanical forces. The dielectric strength of insulation is not directly related to its mechanical strength. The dielectric

strength of insulation may increase initially, even while mechanical strength decreases, as moisture is driven off. Generally the dielectric strength will not fall below its initial level until its mechanical strength has been reduced to near the physical failure point. Thereafter electrical failure may occur because of physical disintegration of the insulation. It must be recognized that how long an insulation will last electrically will depend not only on the class of material used but also on the effectiveness of the physical support for the insulation and the magnitude of the physical forces tending to disrupt it. **The useful thermal life of an insulation is necessarily a question of how much time it is used and how much load is carried during the actual period of use.** The factors of intermittent use and variable load are especially significant in determining insulation life expectancy where the conventional standard insulation temperatures are exceeded either during normal operation or in periods of overload.

Present concepts of insulation life are generally based on an approximate rule of thumb which states that **the thermal life of insulation halves for each 10 degrees C increase in temperature.** There may be some controversy as to whether this is precisely accurate in its constants or over a wide temperature range. However, it is a useful approximation and has been demonstrated to be reasonably accurate by many tests. It provides a very useful tool for interpreting observed life at one temperature to some other temperature. Considerable data are available on both materials and machines which indicate that this is a reasonable concept of life within the normal operating temperature range and a considerable distance upward therefrom.

The concept of variability applies particularly well to insulation life, as engineers have come to recognize that life is a variable thing in insulation as it is in their own experience. To aid in defining the ranges within which most failures occur, the idea of minimum and maximum life was introduced. This span is usually defined as the range within which 95 percent of the failures will probably occur. (The average $\pm 2\sigma$.) During the period between minimum and maximum life, factors other than temperature are usually the actual causes of failure, as thermal aging has rendered the insulation vulnerable to these other causes. Such factors include:

1. Expansion and contraction stresses caused by relative movement of the windings and the surrounding structure, which lead to deterioration of the winding insulation and reduction in life. In general, the larger the machine, the more important this factor is in determining winding life.
2. Mechanical vibration and shock, which may cause insulation damage.
3. Deterioration from exposure to contaminated air and moisture.
4. Electrical stress, particularly as corona is produced.
5. Miscellaneous chance occurrences.

It is now generally believed that the minimum life of insulation can be determined by observing insulation resistance when the winding is exposed to high humidity. Repeated tests during the reliable life of the winding will show a relatively constant value of humidified insulation resistance. When the humidified insulation resistance shows a sudden downward trend, this is believed to be the minimum insulation life. The maximum insulation life will be the point at which the winding loses its bonds and becomes loose so that

vibration and other causes will destroy the insulation physically.

The following formula is used to express the general concept of insulation life as a function of temperature:

$$Y = Ae^{-mt}$$

where A = constant.
e = 2.718.
t = temperature, degrees C.
m = constant.
Δt = temperature increment which decreases life by one-half. Δt is related to m as shown by the table below.

Δt	m
8 C	0.087
10 C	0.0695
12 C	0.058

Current concepts of thermal endurance are shown in Fig. 1–9 for class A, class B, and class H insulations. This illustrates the manner in which each class of insulation has its life reduced by half for a specific temperature increase or increased to double for an equal temperature decrease. **The temperature change to produce this two-to-one change in life is 8 degrees C for class A, 10 degrees C for class B, and 12 degrees C for class H.** This curve also shows the range of expected life between "minimum" and "maximum" boundaries. These boundary curves are based on the average life plus and minus two standard deviations ($\pm 2\sigma$). From statistical analysis methods (see Sec. 1–18 on this subject) this defines the range in which 95 percent of the insulation failures can be expected to occur. It is probable that only random insulation failures (about 2.5 percent) will occur at a shorter time than defined by the minimum-maximum range on the curve. An equal number can be expected to fail at a longer time beyond this range.

Records of actual insulation failures on a large number of similar motors are plotted on Fig. 1–10. Here the motor windings were divided into two groups according to manufacturing conditions and insulating materials used. There is a significant difference between groups. Group 1 has an average life of 100, and the 95 percent failure range extends from 27 (at 2.5 percent failures). On the other hand, group 2 has an average relative life of only 51 and a range (for 95 percent failures) of 11 to 91 relative life.

1–20. CAUSES OF INSULATION FAILURE

An analysis made by an important insurance company several years ago showed that, out of 3,439 failures of electrical apparatus, insulation caused 2,917, or 84.8 percent, of the cases. From this it is clear that **insulation and its proper design, application, and maintenance have a very important part in the successful operation of any electrical machine.** The failure of electrical insulation on machines is frequently associated with serious thermal aging except where there is physical damage from some external source or serious contamination of the insulation with foreign matter. Thermal aging is generally evidenced by loss of moisture resistance and subsequent looseness of the winding and loss of adhesion of the insulation components. The major causes of insulation failure in service may be summarized as:

1. Unusual surge voltages which may be caused by lightning, switching surges or accident on the system.

2. Mechanical damage due to some foreign matter being introduced into the machine or some failure of the mechanical

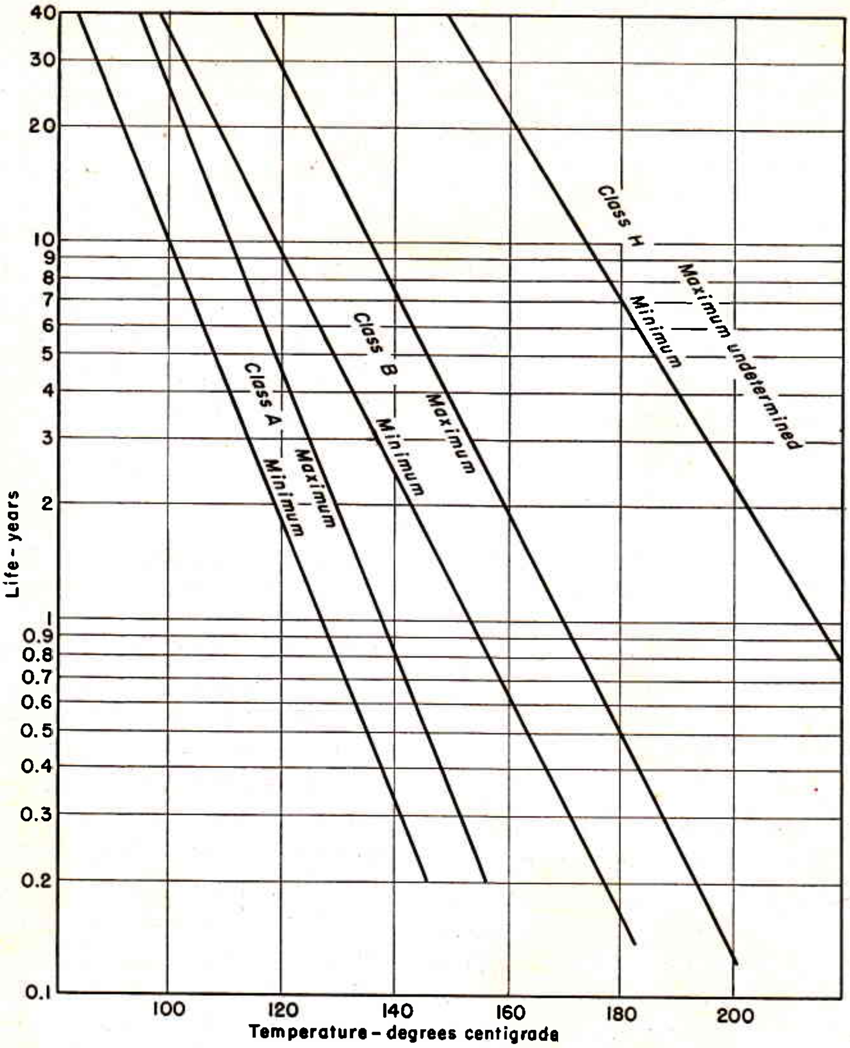

FIG. 1–9. Present concepts of thermal life of standard insulation classes.

supports or ties due to short-circuit conditions.

3. An accumulation of dirt, oil, and other chemical contaminants due to improper operating conditions or faulty maintenance.

4. Improper handling of coils and insulation during winding, which may have damaged them.

5. Faulty design with insufficient margin or the use of unsuitable materials.

6. Corona deterioration at points of high-voltage stress.

7. Moisture absorption, which reduces insulation resistance and dielectric strength levels.

8. Thermal aging as a result of excessive operating temperatures or prolonged operation at normal temperatures, which renders the insulation vulnerable to the many other causes of failure.

It is generally believed that a properly designed winding, carefully manufactured with suitable insulating materials will have a reasonable life expectancy, once it has

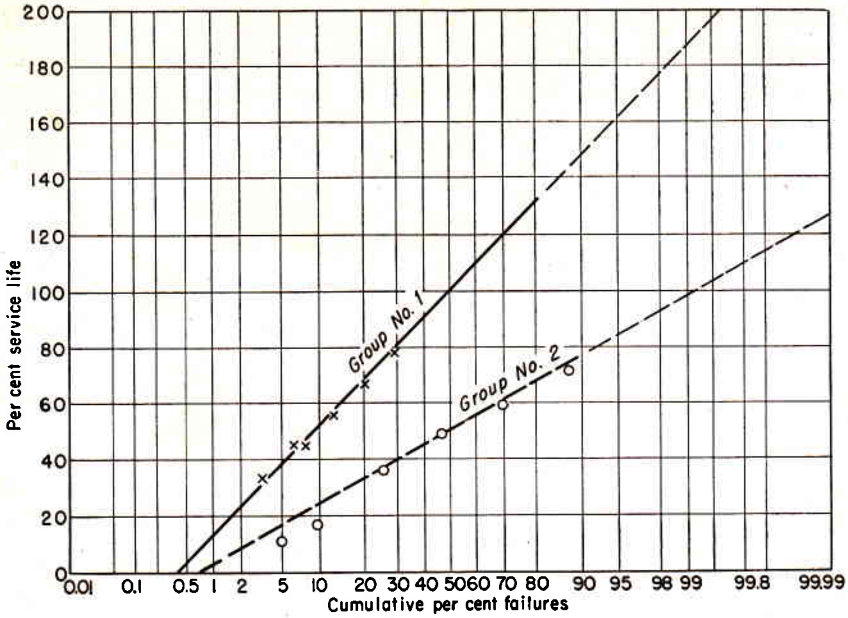

FIG. 1–10. Curve of failure probability on two varieties of insulation under similar service conditions.

passed its acceptance tests, if it is operated within its rating.

1–21. THERMAL CONDUCTIVITY AND SPECIFIC HEAT

It has been stated that the effect of temperature on electrical insulation is very significant in determining life of insulation and windings. Since electrical insulators are generally good thermal insulation, the effect of electrical insulation on windings is to impede the heat flow from windings and thereby raise the temperature of both copper and insulation. Thermal conductivity of an insulating material plays a large part in determining the operating temperature rise of an electrical machine, as it limits cooling.

The heat is generated in electrical apparatus owing to the losses. All these losses must be dissipated into the cooling medium or stored in the mass of the apparatus during periodic loading. During continuous duty, heat storage is not a factor. The parts of a machine will reach temperature equilibrium with various temperature gradients existing between the parts determined by their thermal conductivity and the cooling methods employed. Under continuous uniform loading the specific heat of the various metal and insulating parts has no effect on the attained temperatures. The specific heat (heat storage) of the materials affects the temperatures under short-time loading and determines the time required to attain temperature stability on prolonged operation. Heat storage in insulation is generally low and can be disregarded, as the heat stored in iron and copper parts predominates.

Within an electrical machine heat is generally distributed by means of thermal conduction as the heat flows from the hotter to the cooler parts. Metals have relatively high thermal conductivity (or low thermal resistance), whereas insulating materials have low thermal conductivity (high thermal resistance). Heat dissipa-

tion through space is accomplished by two methods or a combination of them. (1) Hot bodies radiate energy which does not heat the surrounding air. (2) Heat dissipation by convection results from air (or other gas) movement over heated surfaces which transfers heat into the gas. With natural convection the heated gas then moves away, bringing cooler gas into contact with the heated surfaces. With forced convection the cooling gas is blown over surfaces by external means which effectively removes heat from the heated surface into the air stream.

The relative thermal conductivity of materials is of interest in order to obtain an accurate understanding of the heating and cooling of electric machinery. The following tables and statements are intended to provide such a background:

Material	*Thermal Conductivity, Watts per Sq In. per Deg C per In. of Thickness*
Copper (100 C)	9.7
Aluminum (100 C)	5.2
Brass (100 C)	2.7
Tin (100 C)	1.5
Cast iron	1.5
Soft steel	1.19
Porcelain	0.05
Water	1.014
Glass (solid)	0.012
Silicone rubber	0.011
Mica (block)	0.009
Mica and shellac plate	0.009
Phenolic paper laminate	0.006
Rubber	0.005
Asbestos	0.0048
Pasteboard	0.0048
Paper	0.0032
Air not in motion:	
100 C	0.00076
20 C	0.00064

The heat-absorption and -removal properties of the most important materials in electric machinery can be summarized by the following statements:

1. *Copper.* Energy dissipated in copper at the rate of 1 watt per pound will raise the temperature of the copper at the rate of 0.31 degree C per minute if no heat is allowed to escape.
2. *Iron and Steel.* Energy absorbed by these materials at the rate of 1 watt per pound will raise the temperature of the metal at the rate of 0.27 degree C per minute if no heat is allowed to escape.
3. *Air.* Air (at atmospheric pressure) flowing at the rate of 1,650 cubic feet per minute will absorb 1,000 watts with a temperature rise of 1 degree C.
4. *Water.* Water flowing at the rate of 3.8 gallons per minute will absorb 1,000 watts with a temperature rise of 1 degree C.

1–22. ARC RESISTANCE OF INSULATION

Frequently electrical insulating materials are subjected to arcs from various causes. On many materials exposure to arc produces a conducting track (frequently carbon). The ability of a material to resist the formation of such conducting paths, or tracks, when exposed to arcs is referred to as "arc resistance." Commutator insulating V-ring extensions are excellent examples of cases where arc resistance is desired. It is not possible to make any universally applicable generalization concerning the nature of arcs to which insulation may be exposed, as these may vary from high-voltage, low-current arcs to high-current, moderate-voltage arcs. The general property of arc resistance, therefore, must be defined in relation to the test employed. Arc resistance is the ability of a material to withstand exposure to a particular variety of arc for a specific length of time or to withstand a

number of arc applications, each of a known time and energy level. Tests for arc resistance are discussed under electrical testing in Chap. 6.

1-23. CORONA

Corona is generally defined as the form of electrical discharge which occurs between conductors when the critical voltage of the intervening gas is exceeded. The conductors are then surrounded by a visible (and sometimes audible) layer of ionized gas which increases in intensity as the voltage is increased. When gas alone separates the two electrodes, the formation of corona is usually followed by breakdown and arc-over of the separating space. Corona will sometimes occur, on a combination of solid and gaseous insulation, which is not followed by breakdown unless the total voltage is in excess of the dielectric strength of the solid insulation alone. When the voltage is such that corona occurs, the gas is ionized to the point where the voltage across the gas space will collapse. This places almost the full voltage across the solid insulation. Corona frequently occurs on transmission lines even where the spacing is quite large. It may also occur in high-voltage electric machinery where very small spacing exists.

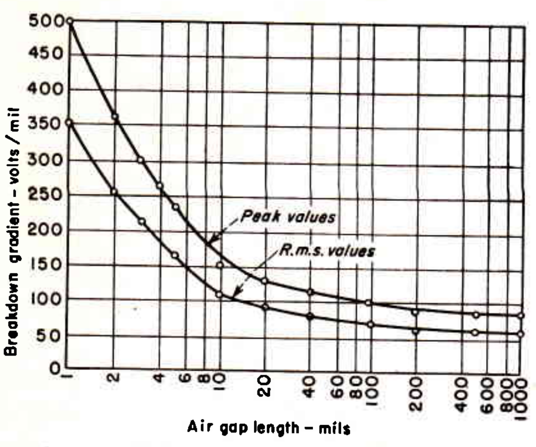

Fig. 1-11. Corona starting voltage of air.

The discussion of voltage distribution in an earlier section gives the method for calculating the voltage distribution across insulations that have different dielectric constants. The corona starting voltage of a system containing solid insulation and air spacing can be calculated from the following formula:

$$V_c = E_a\left(t_a + \frac{t_s K_a}{K_s}\right)$$

where V_c = corona starting voltage of system.

E_a = corona starting gradient in air in volts per mil (see Fig. 1-11, as corona starting voltage is essentially the same as air-breakdown gradient).

t_s = thickness of solid insulation, mils.

t_a = thickness of air film, mils.

K_s = dielectric constant of the solid insulation.

K_a = dielectric constant of air (1).

Corona itself is not harmful; however, there are serious secondary effects which result from the production of powerful oxidizing agents in an intense electrical field. Ozone is produced, which accelerates oxidation of adjacent organic materials. Nitrogen oxide components, produced by the ionization of the air, combine with water to form acids that attack organic materials; these also can corrode metal. Organic insulations such as varnishes, bonds, and cellulose are rapidly oxidized in a strong corona field. They become weak mechanically, are embrittled, and ultimately may be eaten away. Mica and glass are unaffected by corona and the oxidizing agents produced by corona because of their inert, inorganic composition. Organic resin bonds

for mica and organic varnish treatments for glass fabrics may be seriously affected by corona action. Silicone-resin bonds and treatments are much more resistant to corona. Natural rubber and organic synthetic rubbers are particularly susceptible to corona oxidation, while silicone rubbers remain unaffected for long periods.

1-24. EFFECT OF MOISTURE ON INSULATION

Moisture and humidity affect insulation in two important ways. Where the insulation is porous, moisture will be absorbed into the pores of the solid insulation, reducing its insulation resistance. As moisture wets the surface, a thin film of water may be formed covering the whole surface and rendering it relatively conducting.

Water distributed throughout the volume of an insulation produces interfacial polarization. This will cause an increase in capacitance and power factor as well as a reduction in insulation resistivity. The degree by which moisture absorbed into insulation will affect these factors depends on the relative humidity of the surrounding air and also upon the frequency at which measurements are made on the insulation. The rate at which porous insulation absorbs water and the retention of the moisture depend upon the porosity of the material. At 100 percent relative humidity and commercial frequencies, the capacitance of an insulation may double and the power factor may approach 100 percent, with the insulation resistance being reduced by a factor of as much as a million to one.

The effect of surface films of moisture on insulation is largely determined by the ease with which water wets the surface. This is in turn determined by the contact angle between the insulation surface and a drop of water on that surface. In general porous materials that have high volume moisture absorption will have surfaces that are easily wet. Microscopic roughness of the insulation surface usually helps the formation of moisture films, whereas very smooth surfaces are more difficult to wet. Some materials, such as wax, polystyrene, silicones, and a few other polymers, successfully prevent the formation of a continuous film of surface moisture. **The silicones as a group are not easily wet and resist the formation of moisture films on their surfaces. This is highly advantageous for insulation in humid locations.**

The condition of an insulation surface is quite important in determining the effect of moisture on it. **The presence of dust, dirt, and other contaminants (even perspiration) greatly aids in wetting the surface.** Thin moisture films may have so high a conductivity that they reduce the insulation resistance of an insulator by a factor of several orders of magnitude. Since there are no insulators that are unaffected by moisture, either by absorption into the volume or by collection on the creepage surfaces, it is necessary to treat nearly all insulators to fill their pores and to coat the surfaces to minimize the deleterious effects of moisture and humidity. Even such treatment is not the complete answer, as all resins transmit moisture vapor to some degree. **Treatment should be understood to produce only a relative improvement and must not be thought to provide an impervious barrier to moisture penetration or a completely nonwetting surface.**

2. Classes of Insulation and Properties of Insulating Materials

The purpose of insulation in electric apparatus is to separate circuits and conducting parts of different potential. This is accomplished in three distinctly different ways, namely:

1. Separation in an insulating fluid (usually air).
2. Creepage across an insulating surface (or through porous insulation).
3. Solid dielectric barrier (or a continuous insulating film) having intrinsic dielectric strength.

On most apparatus, all three methods of insulating are employed, as it is generally not practical completely to enclose all of any circuit component in a solid dielectric sheath. **It is highly desirable to use the dielectric barrier method because of the tremendous increase in dielectric strength level obtainable within a given space in comparison with the other two methods of insulating. It is in the category of dielectric barriers where the differences in materials play an important role.**

The dielectric strength of composite insulation is dependent upon the technique of fabrication as much as upon the inherent characteristics of the component materials. Identical materials may be assembled in different manners though they may appear to be equivalent and yet have breakdown strengths differing by as much as 10 to 1. Where fibrous materials and treating compounds are combined, the degree of consolidation of the composite materials into a solid barrier is the primary factor in determining the insulation breakdown level. Where mica is employed, the manner in which the mica flakes are overlapped is important. The degree of impregnation and consolidation is also significant, especially at higher voltages. Where varnish treatment is depended upon for high dielectric strength, it has been found that only films of varnish have breakdown strength appreciably greater than creepage spacing. Furthermore multiple films are necessary for a reliable dielectric barrier, as single films always contain pinholes. Frequently

the importance of these factors of fabrication processing and their effect on insulation breakdown level are not fully understood and appreciated. The properties of the insulating materials used are important, but the intrinsic potentialities of good insulating materials are realized only where proper fabrication techniques are employed.

2-1. GENERAL REQUIREMENTS OF INSULATION

Electrical insulating materials have been defined as those materials which inherently offer a very high resistance to the flow of electric current. Their main original purpose is to direct and guide the current in its proper path along the conductors. The first purpose of insulation is electrical, and in the early days of the electrical industry this was its only purpose. Subsequently design engineers have imposed thermal and mechanical duties on insulation as well as its electrical functions.

As the insulation requirements grew in the early days of electric machinery, the problem of higher voltages was met with more layers of insulation. This construction relied entirely on the additive dielectric properties of multiple thicknesses of insulation. In the beginning, insulations generally consisted of untreated cotton tapes. The first treatments applied to insulation consisted of solutions of gums in alcohol which were chiefly comprised of shellac and boiled linseed oil.

Some of the very early machines employing these original kinds of insulation are still in operation, probably because they were operated at low temperatures and not subjected to severe physical forces or to moisture and chemical contamination. With the electrification of modern industry and transportation, motors have been subjected to contamination from chemicals and conducting dusts as well as to the destructive effects of moisture and heat; therefore, the original types of insulation are no longer suitable. The success of an insulation for a particular application will depend largely on the service conditions. It is therefore quite difficult to apply insulation with the mathematical precision which is used in the solution of mechanical and electrical design problems. Instead, the selection of insulating materials and their application have become largely empirical, and insulation systems have generally been designed by cut-and-try methods.

A great many factors are involved in the selection of suitable insulation for a specific application. Close cooperation is essential between the insulation engineer and the electrical and mechanical designers. One of the greatest problems in coordinating electrical, mechanical, and insulation design is that there are few suitable "yardsticks" for measuring insulation properties. Materials are quite frequently evaluated separately under vastly different conditions from those under which they are used in machinery. Furthermore, the care with which insulating materials are handled and fabricated has a great deal to do with their ultimate properties in machines. In many cases it may be found that insulating materials selected from handbook data may be unsuitable for the particular use because of special handling and fabrication problems. In order to evaluate insulating materials for specific applications, the following test data should be available:

1. Laboratory tests of basic material properties.
2. Tests and experience to evaluate the effect of application methods and processing on insulation properties in the final form.

3. Service tests to evaluate expected life of completed apparatus under actual operating conditions.

It is advisable to review the requirements for insulation in electric machinery as a preliminary step before considering the characteristics of available materials. The primary requirement may vary depending upon the design and application of a particular machine. The following sections review the basic requirements for insulation as applied to electric machinery.

2-2. PHYSICAL PROPERTIES

Physical properties are of particular importance during manufacturing when **most mechanical abuse of the insulation occurs.** Furthermore, the insulation must have adequate mechanical strength in the final form of the completed winding to withstand all the mechanical forces that it may encounter during operation.

1. Flexibility is required to withstand forming and bending of insulations during application and winding without serious loss of the electrical properties.
2. Abrasion resistance is necessary to withstand the handling of materials and parts during fabrication and assembly, particularly during installation in the machine.
3. Tear strength is an important characteristic, particularly where isolated sheets of insulating material extend to provide creepage distance.
4. Shear strength is an important property of insulations, especially where centrifugal forces exist such as on rotating field coils.
5. Flexural strength is quite important on insulating supporting members such as washers, angles, and wedges which bear the brunt of physical forces, especially on rotating parts.
6. Tensile strength is also important on various insulation parts, particularly during winding and fabrication.
7. Bond strength is especially significant on mush-wound coils which may be subjected to vibration. It is also important on armature coils between the turns in the straight part as well as between the turns of rotating field coils.

2-3. ELECTRICAL PROPERTIES

1. Dielectric breakdown strength is the property given the greatest emphasis for very obvious reasons. **It should be fully realized that dielectric strength of an insulating material in the sample sheet is not so significant as the dielectric strength of the material in its final form in a winding.** The strain of forming and winding may impair the dielectric strength of some materials.
2. Resistivity should be high in order to minimize leakage current and heating of the dielectric.
3. Power factor should also be low, as dielectric loss is undesirable and produces heating of the insulation. While insulation power factor is not in itself significant in machines operating at commercial frequencies, **a low dielectric loss is a desirable property in all insulations.**
4. Dielectric constant is of significance because it affects the voltage distribution on insulations in series. At the higher operating voltages the use of one material with a high dielectric constant may result in overstressing those parts with a low dielectric constant, such as the adjacent air spaces.
5. Corona resistance is of particular importance at higher operating voltages but not so important at low voltages (below 6,000 volts).
6. Arc resistance and track resistance measure the ability of a material to with-

stand leakage currents or arcs over the surface without forming permanently conducting paths. This property is most important adjacent to commutators and collector rings, where creepage surfaces are exposed to such phenomena, but is also important in many other applications.

7. Moisture resistance is one of the most important properties of insulations. Nearly all insulating materials have very good electrical properties when dry but are affected by moisture to a varying degree. The adverse effect of moisture on the desired property of a material is one of the best yardsticks for determining its practical usefulness.

2-4. CHEMICAL PROPERTIES

1. Resistance to oils and common solvents is of considerable importance in the practical value of insulations. Oils and oil vapors are quite prevalent in electric machinery. Furthermore, insulations often require cleaning with solvents. It is important that neither oils nor solvents damage the basic insulation or the hard, glossy surface of the treatment.

2. Resistance to weak acids and alkalies should be reasonably good, although it is generally not practical to provide resistance to high concentrations of such contaminants.

3. Ozone degradation of insulation is primarily of importance only on higher voltage machines (6,000 volts and above) where corona is present.

4. **Inflammability of insulation is an important property, as fires which follow electrical failures frequently do more damage than the original insulation failure. On shipboard, especially in closed areas, the fumes resulting from fires may be a serious hazard to personnel.**

5. Thermal stability of insulation is one of the most important properties of insulation. It is a significant factor in the life of windings.

2-5. TEMPERATURE CLASSIFICATION

Temperature limitation is an important factor in determining the rating of electric machinery. The permissible operating temperature in turn is dependent upon the class of insulation used. Industry standards (AIEE, ASA, NEMA, and others) as well as Navy standards define and classify insulations as follows:

Class O, consists of cotton, silk, paper, and similar organic materials when neither impregnated nor immersed in a liquid dielectric.

Class A, consists of (1) cotton, silk, paper, and similar organic materials when either impregnated or immersed in a liquid dielectric; (2) molded and laminated materials with cellulose filler, phenolic resins, and other resins of similar properties; (3) films and sheets of cellulose acetate and other cellulose derivatives of similar properties; and (4) varnishes (enamels) as applied to conductors.

Class B, consists of mica, asbestos, fiber glass, and similar inorganic materials in built-up form with organic binding substances. A small proportion of class A materials may be used for structural purposes only. (The electrical and mechanical properties of the insulated winding must not be impaired by application of the temperature permitted for class B material. The word "impaired" is used in the sense of causing any change which could disqualify the insulating material for continuous service. The temperature endurance of different class B insulation assemblies varies over a considerable range, in accordance with the percentage of class A materials employed and the degree of dependence placed on the

organic binder for maintaining the structural integrity of the insulation.)

Class C, consists entirely of mica, porcelain, glass, quartz, and similar inorganic materials.

Class H, consists of (1) mica, asbestos, fiber glass, and similar inorganic materials in built-up forms with binding substances composed of silicone compounds (or materials with equivalent properties); (2) silicone compounds in rubbery or resinous forms (or materials with equivalent properties). A minute proportion of class A materials may be used only where essential for structural purposes during manufacture. (The electrical and mechanical properties of the insulated winding must not be impaired by the application of the temperature permitted for class H material. The word "impaired" is used in the sense of causing any change which could disqualify the insulating material for continuous service.)

The basic limitations placed on temperature by these standards can be summed up as shown in the table below.

The values given are generally considered as basic reference standards (AIEE Standard No. 1), but there are numerous exceptions in specific industry and apparatus standards. In Chap. 1 it is pointed out that "how long an insulation will last depends not only on the class of material used and its operating temperature but upon the physical support for the insulation and the physical forces tending to disrupt it." Some industries and certain classes of apparatus have special temperature limits which are considerably in excess of the basic standards. Examples of these special classes are magnet coils for industrial and railway control plus motors and generators for traction apparatus.

2-6. BASIC INSULATING MATERIALS

The major basic insulating materials are reviewed first and their general properties and characteristics discussed without describing the particular forms into which they are fabricated, as that phase will be covered in subsequent sections of this chapter.

2-7. *Cellulose*

Cellulosic products constitute a very important class of insulating materials. For electric machinery they are used in the form of paper, pressboard, yarn, and cloth. Most of the cellulose used in the electrical

Insulation class	Hottest spot temperature, deg C	Permissible rise, deg C*	
		By thermometer*	By resistance or embedded detector*
O	90	35	45
A	105	50	60
B	130	70	80
C	Not established		
H	180†	100	120

* Based upon a 40 C ambient and a hot-spot allowance with the thermometer method of 15 C for class O and class A insulation; 20 C for class B; 40 C for class H and a hot-spot allowance with the resistance method of 5 C for class O and class A insulation; 10 C for class B; 20 C for class H.

† Navy specifications list 200 C as hottest spot temperature for class H insulation.

industry is derived either from cotton linters or from wood. Flax, hemp, rice, and various other plant straws are less important sources. Old rags, originally made of cotton, are an important secondary source. Cotton linters contain up to 90 percent cellulose, while wood contains from 40 to 60 percent cellulose. Cellulose belongs to a class of materials known as "natural high polymers." It consists of carbon, hydrogen, and oxygen. The repeating unit in the polymer chain is $(C_{12}H_{20}O_{10})_n$, where n may vary from 30 to 2,000 depending on the source. Cellulose owes its unique combination of properties, namely, strength, elasticity, and flexibility, to its long chain structure. These, combined with good electrical properties and low cost, make it a most useful insulating material when properly dried and impregnated. Where dielectric strength is a primary consideration, paper is to be preferred over cloth, since the closely matted fiber structure of paper acts as a barrier to the free movement of ionic charges. If, however, high mechanical strength is the main requirement, then the relatively stronger woven fabric is more desirable.

Cellulosic materials are not without disadvantages. The three most serious ones are (1) moisture sensitivity, (2) lack of thermal stability at the higher temperatures, and (3) necessity for impregnation with a liquid or varnish to obtain good electrical properties. **Since cellulose absorbs moisture so avidly with consequent serious effect on its electrical properties, it is practically never used in important electrical applications without thorough drying and impregnation.** Even aside from reducing the possibility of the reabsorption of moisture, impregnation replaces the air normally present in the fiber interstices, thus markedly improving dielectric strength. Short-time 60-cycle dielectric strengths of the order of 1,000 volts per mil and impulse strengths several times this value are commonly observed on impregnated paper or pressboard. The effects of moisture can be minimized by careful drying and treatment of cellulose products with oils or resins, but the low thermal stability of these materials is not so easily remedied. For this reason the continuous operating temperature of electrical apparatus employing essentially cellulosic insulation is usually limited to a maximum value of 105 C except for short periods of overload. When cellulose is destroyed thermally, it breaks down into water, carbon dioxide, and **carbon monoxide.** Carbon monoxide is the most dangerous product of decomposition from the standpoint of its toxic hazards, especially in enclosed spaces on both surface vessels and submarines. Water is, of course, the most harmful product electrically. An important secondary effect is the loss of mechanical strength when the cellulose is broken down thermally.

In spite of the limitations of cellulosic materials, they have an important place in the electrical insulation field. Their physical strength, ease of fabrication into thin members, and adaptability to commercial processes make their use highly desirable as bases for the building of the higher temperature classes of insulation. Therefore, small percentages of cellulosic materials are permitted in both class B and class H insulations.

2-8. *Asbestos*

The general term "asbestos" refers to the fibrous classes of the minerals "serpentine" and "hornblende." There are many varieties of asbestos differing considerably in chemical and physical properties. The most important commercial types are chrys-

otile and amphibole. The former is essentially a compound silicate of magnesium, iron, calcium, and generally some manganese, and the latter is similar in composition but often contains aluminum. Asbestos fibers from different parts of the world differ considerably in composition as well as in chemical and physical characteristics. They may differ considerably in flexibility, contained waters of crystallization, color, strength, physical properties of the fibers, resistance to acids and heat, contamination by conducting particles of iron oxide, and other respects. They are similar, in general, in that they are heat resistant, become brittle when dehydrated by excessive heating, contain approximately 2 percent of hygroscopic moisture, and are poor resistors to electricity unless thoroughly dry. Canadian chrysotile asbestos is best suited for spinning because of its fineness of fiber, flexibility, and tensile strength. It contains a considerable number of magnetic oxide of iron particles which are conducting and may cause electrical failures under certain conditions. It is attacked by hydrochloric acid and sulphuric acid. It will withstand a temperature up to 300 C without loss in strength. At 400 to 500 C it will lose approximately 3 percent of its water of crystallization in ½ hour. At 600 C or over it will lose practically all its water of crystallization and become brittle and weak. Chrysotile asbestos from Arizona contains considerably less magnetic oxide of iron than the Canadian type and for this reason is used in certain grades of asbestos paper for specific applications. It can be spun into yarn, but it is weaker and more brittle than the Canadian chrysotile type. Amphibole asbestos is much more heat resistant than chrysotile asbestos, withstanding a temperature of approximately 1000 C without much alteration. It is not acted upon by hydrochloric and sulphuric acids. It can be spun into yarns. The electrical resistance of asbestos may be increased by treating with boric acid solution in distilled water. Crocidolite asbestos (African) differs in chemical composition from either the chrysotile or amphibole asbestos and is very much more resistant to sulphuric acid, harsher, and more brittle than chrysotile.

Asbestos fibers have become available in a different form through improvement in processing. Means have been found for preparing asbestos fibers to smaller dimensions and for the removal of impurities and conducting particles to a degree not commercially feasible in the past. This purified fiber is combined with a binder and a filler by special papermaking processes. The resulting paperlike material has found a number of uses in electrical apparatus. It is quite similar in appearance to cellulosic paper, being thin and flexible, but is 100 percent inorganic. It can also be treated with organic and silicone resins for further improvement of its electrical properties. Two varieties of this asbestos paper are available under the trade names Terratex and Quinterra. This insulation is primarily useful for wire covering and as insulation between turns or strands where low-voltage gradients exist. This material possesses an unusual combination of high dielectric strength, good thermal life, and incombustibility. Designers can utilize the thinness of this insulation to improve space factor or obtain a higher factor of safety on class B turn insulations.

2–9. *Fiber Glass*

Glass has long been recognized as excellent electrical insulation, but its use was limited by the form in which it was available. As a hard, brittle, vitreous material it had definite and rather narrow limita-

tions. With the development of fiber-glass yarns, a vast new field was opened to its use electrically. Its thermal endurance, moisture resistance, chemical resistance, physical strength, and thermal conductivity made it universally applicable as an insulating material. The art of spinning glass into threads that could be used in textiles is not new, as a patent was issued in 1890 covering the insulation of magnet wire with glass fibers. It was only in the late 1930's that processes and machinery were developed for producing these minute glass fibers economically in great quantities of uniform size and quality.

Two types of fiber-glass yarns are available for use in the electrical industry: continuous-filament yarns and staple fiber yarns. A special electrical quality glass is used in both types; however, the method of manufacture and the characteristics of the finished yarns differ widely. The continuous-filament yarns are the most generally used type of fiber-glass yarn—for both woven products and wire and cable insulations. They are made by twisting and plying strands of continuous glass filaments. These filaments are mechanically drawn from molten glass and resemble natural silk or rayon in general appearance. Staple fiber yarns are made by drafting and twisting slivers (rhymes with "fibers") of fine-staple glass fibers. The individual fibers vary in length up to 15 inches, with an average length of about 9 inches. They are produced by the blast drawing of molten glass and resemble staple cotton or wool fibers in general appearance, although glass fibers are longer than these natural fibers. In both processes of making fiber-glass yarns, a small amount of lubricant is added to the fibers to make their subsequent processing more efficient. This lubricant minimizes the friction between fibers and lessens fiber breakage and self-abrasion, acting similarly to the natural oils present in organic fibers.

Both continuous-filament and staple fiber yarns are made with fibers of controlled diameters, of three nominal diameters, 0.00023, 0.00028, and 0.00038 inch. Each type of yarn, differing principally by the number and diameter of the individual filaments used in its construction, gives the woven or braided products slightly different characteristics of flexibility, fuzziness, and strength. Also, yarn cost (and proportionally, the cost of any woven or braided product) will vary in relation to the type of yarn used. The larger fiber yarns, owing to greater production rates, are lower in price than the finer fiber yarns. Hence, yarn characteristics and cost are factors to recognize and consider in the proper selection and use of any fiber-glass yarn or fabricated product.

In general, the finer the filament diameter in a yarn, the smoother and more flexible is the yarn and woven product. Fine-filament yarns and products from these yarns are generally a little less fuzzy, slightly more flexible, and less subject to breaking on sharp bending than coarser fiber products. Conversely, as the filament or fiber diameter in a yarn is increased, the product becomes very slightly more "wiry," is a bit more subject to abuse from abrasion, and has a few more surface "hairs." However, it must be emphasized that these physical differences between the various sizes of textile fibers are rather minute and in many cases need no consideration. The coarser fiber yarn products have found excellent use in many woven and braided applications.

Glass has outstanding properties as electrical insulation which can be summarized as:

1. Thermal endurance is outstanding. **It overcomes thermal aging, which is one of the greatest enemies of insulating materials.** Glass is inorganic and is therefore unaffected by any temperatures experienced in electric machine operation. In this respect it has a tremendous advantage over other fibrous materials, especially the cellulosic type.

2. Moisture resistance is very high, as water cannot be absorbed into the structure of the glass filaments. Water can, of course, collect on the surface of and between the filaments. Therefore the problem of moisture resistance becomes one of selection and application of impregnants and coatings.

3. Chemical resistance is an outstanding property of fiber glass. The nature of the fiber makes it far more resistant to most gases and liquid chemicals than organic types of fibers.

4. Physical strength of individual glass fibers may be greater than that of steel. Glass yarns are very strong, and the tapes may be made much thinner than other fabrics and still have ample tensile strength.

5. Thermal conductivity is an important characteristic of electrical insulation. Glass fibers may be arranged in compact form so that they have high thermal conductivity. On the other hand, they may also be used as thermal insulation by employing them to break up the air space into dead-air cells. However, the type of fiber-glass insulation used in electric machinery inherently has good thermal conductivity, especially when thoroughly varnish-treated.

6. Space factor of fiber-glass insulation is generally much better than that of its competitors in the textile field. Because of its strength it can be made much thinner than other textiles.

A frank discussion of a new material, such as fiber glass, must necessarily point out some of the limitations and problems associated with its application to electrical insulation.

1. Glass fibers without any coating are abrasive enough to cut each other. Their successful operation in a textile requires lubrication of the individual fibers, which is done as part of the fiber-making process. This lubrication is quite successful, but this limitation must be understood to explain some phenomena observed when glass textiles are heated at elevated temperatures. When the lubricant is destroyed, glass fabrics readily abrade. The abrasion resistance of glass fabrics can be further improved very greatly by varnish treatment. Thus it can be seen that the abrasion resistance of glass fibers and the textile combinations is dependent upon the resinous treatment. There are further limitations due to the presence of lubricant or sizing on the glass fibers. The sizing itself is not a good insulator and in some cases prevents the varnish from adhering to the glass. For certain insulations, it has been necessary to remove the glass sizing either partially or completely by heat cleaning or chemical cleaning in order to obtain higher bond strength or to improve electrical properties. The varnish treatment must be applied immediately following the cleaning and before the glass fibers have a chance to abrade each other. A need still exists for a glass-fiber sizing which will be compatible with the resin or varnish used and which will have satisfactory thermal and electrical properties.

2. Glass fabrics are primarily spacing insulation. **They have no dielectric barrier effect in themselves and can only support a voltage equal to the air-spacing**

breakdown. To become dielectric barriers they must be coated with resins. Therefore, the dielectric barrier effect of fiber-glass insulations is attributable to the resin treatment selected and the method of processing employed. Likewise the thermal endurance of a varnished glass is dependent upon the treatment rather than upon the glass itself.

2–10. *Mica*

Mica is one of the oldest insulating materials in the electrical industry. It has maintained its position of importance, despite the inroads of synthetics, through its outstanding combination of dielectric and physical characteristics. It has high dielectric strength and low dielectric loss as well as high surface and volume resistivity. It also has excellent thermal stability, being infusible and noninflammable. When mica is subjected to temperatures beyond its safe limits, it simply dehydrates and subsequently calcines, becoming silvery and opaque and losing its mechanical strength and dielectric properties. Mechanically, mica has high shear and tensile strength. Chemically, it is relatively inert, being unaffected by water, conventional solvents, alkalies, and acids, with the exception of hydrofluoric and sulphuric acids. Mica is vulnerable to oil, for the oil works its way into the laminae and separates them.

Mica in some form and quality may be found in all parts of the world, mixed with clay, feldspar, and quartz. Of the seven recognized varieties only muscovite and phlogopite are of any industrial importance. Muscovite mica, more commonly called white or ruby, is generally found in a coarsely crystalline intrusive igneous rock known as pegmatite in which the crystals or blocks of mica are segregated near the point of contact with adjoining rock. Phlogopite, or amber, mica occurs in a somewhat similar rock which is basic rather than acidic and is associated with limestone. India is the chief source of muscovite mica for commercial use in electrical insulation. However, muscovite is also the type of mica most commonly found in the United States, although phlogopite deposits are known. Phlogopite comes principally from Canada and Madagascar and is a poor second from a productive viewpoint, since it accounts for less than one-fifth of the total world mica output.

Chemically, muscovite mica might be called hydrogen potassium aluminum silicate. Phlogopite, similarly, is a hydrogen potassium magnesium aluminum silicate. Both of these contain water of crystallization, about 4.9 percent in muscovite and 3.2 percent in phlogopite. It is this water which is driven off when mica is exposed to excessive temperatures that gives the flakes a silvery, puffy appearance. The colors of both types vary greatly. However, when the color of mica is under consideration, judgment should be made only on sheets which are at least $\frac{1}{32}$ inch thick, since in thin sheets muscovite mica appears colorless and phlogopite much lighter than when in blocks. Muscovite is commonly available in white, green, yellow-brown, and ruby. Phlogopite comes in amber, brown, and wine. Characteristic red or black stains are a frequent source of trouble in mica. If these are oxides of iron, manganese, or copper, the insulating properties of the mica are impaired. Such spotted mica can safely be employed for low-voltage work but is unsuitable for high-voltage or higher frequency applications.

The hardness and heat resistance of the mica must be taken into consideration for the different applications in the electrical

industry. Amber mica is softer than white and may be used for commutator segments where the finished commutator is not undercut. The amber mica wears with the copper, whereas white mica does not wear so readily and causes arcing and excessive brush wear.

Mica is used in electrical insulation in the form of splittings which are generally about 1 mil in thickness. These are split by hand after the foreign material has been trimmed away from the edges of the mica block as mined. Commercial splittings are graded according to usable area, thickness, and uniformity. The American standard grades of mica splittings are tabulated in Fig. 2-1 for muscovite and Fig. 2-2 for phlogopite.

FIG. 2-1. STANDARD CLASSIFICATION AND GRADING OF MUSCOVITE (WHITE) MICA SPLITTINGS

NEMA grade	Commercial grade No.	Size	Packing	Thickness per 10 films, in.
A	No. 5 first quality	3 to 5⅞ sq in.	Book form (1) Loose with powder (2) Loose (2)	0.006-0.008 0.007-0.010 0.007-0.010
B	No. 5½ first quality	1½ to 2⅞ sq in.	Book form (1) Loose with powder (2) Loose (2)	0.006-0.008 0.007-0.010 0.007-0.010
C	No. 5½ second quality	At least 75 percent of splits to be 1½ to 2⅞ sq in.; balance to be at least 1 to 1⅜ sq in.	Loose with powder (2) Loose (2)	0.007-0.010 0.007-0.010
D	No. 6 first quality	At least 60 percent of splits to be 1 to 1⅜ sq in.; balance to pass over screen of ¾-in. mesh	Loose with powder (2) Loose (2)	0.007-0.010 0.007-0.010
E	No. 6 second quality	At least 50 percent of splits to be 1 to 1⅜ sq in.; balance to pass over screen of ½-in. mesh	Loose (3)	0.007-0.011
F	No. 7	Splittings shall be of a minimum area of ¾ sq in. and should pass over a screen of ½-in. mesh	Loose (4)	0.007-0.012

(1) Films must be of sound clean muscovite mica, free of all spots and stains, evenly split to specified thickness, without thick edges or corners. Edges must be absolutely clean cut.

(2) Same as (1), except that edges may be slightly irregular in shape.

(3) Same as (2), but may contain not more than 5 percent slightly weathered or earth-stained films. No mineral stains allowable.

(4) Same as (2), but may contain not more than 7½ percent slightly weathered or earth-stained films. No mineral stains allowable.

General Note: The above surface areas do not refer to the total areas, but to the rectangular sizes that each grade should produce.

Extracted in part from NEMA publication No. 46-117.

FIG. 2–2. STANDARD CLASSIFICATION AND GRADING OF PHLOGOPITE (AMBER) MICA SPLITTINGS

NEMA grade	Commercial grade No.	Size	Thickness per 10 films, in.	Remarks
N	No. 5 first quality Book form Loose with powder Loose	3 to 5 1/8 sq in.	0.007–0.010	See Note 2
O	No. 6 first quality Loose with powder Loose	At least 60 percent of splits to be 1 to 1 3/8 sq in.; balance to pass over screen of 3/4-in. mesh.	0.007–0.010	See Note 2
P	No. 6 second quality Loose	At least 50 percent of splits to be 1 to 1 3/8 sq in.; balance to pass over screen of 1/2-in. mesh.	0.008–0.012	See Note 3
R	No. 7	Splittings shall be of a minimum area of 3/4 sq in. and should pass over a screen of 1/2-in. mesh.	0.008–0.012	See Note 3

Note 1. Grade areas: The above surface areas do not refer to the total areas but to the rectangular sizes that each grade should produce. For example, No. 5 grade should be large enough to cut rectangular pieces measuring 1 1/2 by 2, 2 by 2, 2 by 2 1/8 inches, etc.

Note 2. Films must be free from stone or other mineral inclusions, evenly split to specified thickness, absolutely clean cut, and without thick edges or corners.

Note 3. Same as Note 2, but edges may be slightly uneven.

Extracted in part from NEMA publication No. 46–117.

2–11. INSULATING VARNISHES AND RESINS

The most important substances from the point of view of imparting life and dependability to electrical apparatus are the insulating varnishes. These materials are important not only as insulators in themselves but also as a protection to the other insulating materials, especially those of a fibrous nature such as the cotton or glass fabrics, tapes, and cellulosic or asbestos papers. The resulting protected insulation is of high dielectric level ranking next to mica products in insulating properties. Varnishes are used in the treatment of all kinds of windings.

Varnishes can be defined as usually being composed of a heat-blended mixture of a drying oil and a resin, usually dissolved in a solvent. All degrees of actual chemical combinations of resin and oil are possible, from simple solution of a resin in an oil to almost complete "tying-in" of the oil into the molecular structure of the resin. Insulating varnishes are manufactured from suitably prepared vegetable and animal oils, natural gums or resins, synthetic resins and pitches, or asphalts, thinned to a proper working consistency with solvents. They are usually classed as clear or black varnishes, the former now including a wide range of different natural and synthetic resin varnishes and the black being asphaltic-base materials. Varnishes are also classed as to their drying properties and uses, for example, air drying, quick baking, plastic, finishing, and impregnating. The designations of paints and varnishes are graphically illustrated in Fig. 2–3.

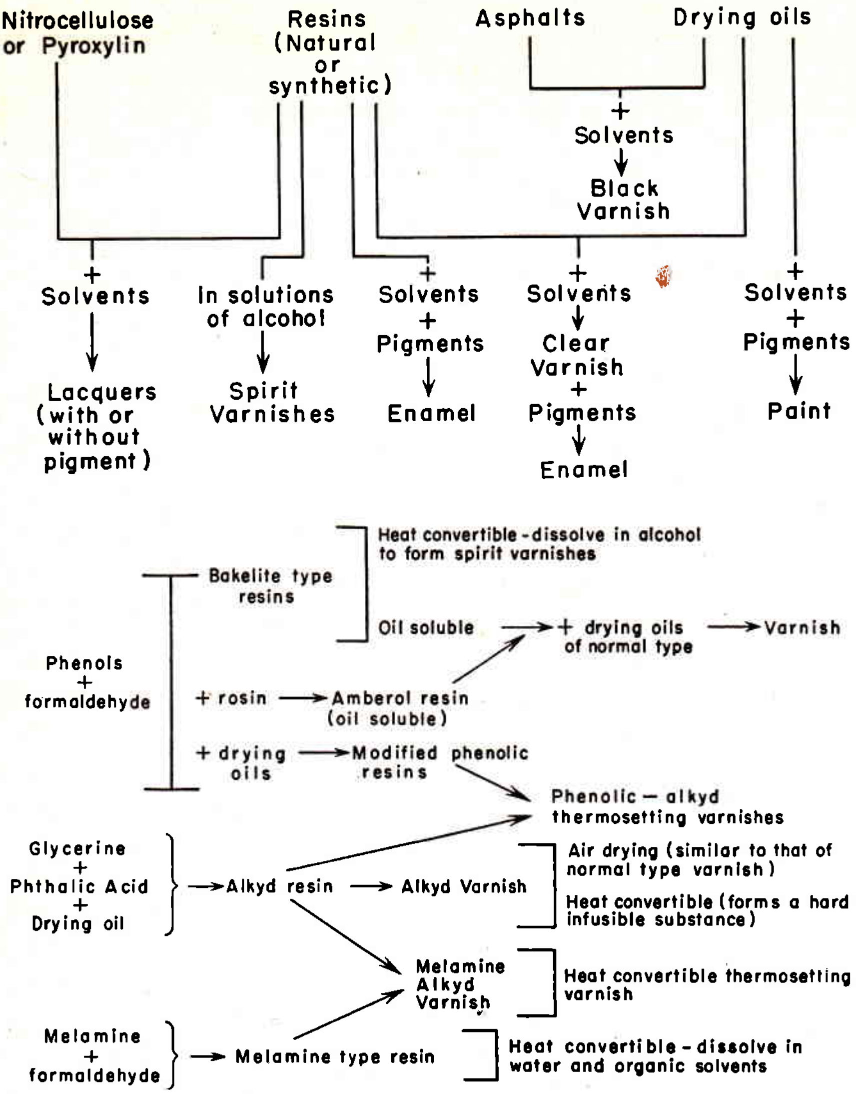

FIG. 2–3. Varnishes, paints, and enamels chart.

Alkyd varnishes and a few phenolic resin varnishes differ from the ordinary "oil-gum" varnishes in that, instead of melting a resin and dissolving it in an oil with little or no chemical reaction between them, the alkyd or phenolic resin is formed in contact with the drying oil and combines in some cases practically completely with it, so that the resulting resin contains drying oil. This resin is then simply dissolved in proper solvents to produce the varnish. The superiority of these synthetics is at least in part the result of this intimate tie-in of resin and oil. "Short oil" and "long oil" are terms relating to the "oil length" of a varnish, a designation which states the ratio of drying oil to resin in the formula.

Spirit varnishes are usually solutions of shellac, rosin, or other alcohol-soluble resins in alcohols; usually they contain no oil. Spirit varnishes are used for quick finishes, sizing, and coating of paper. Shellac is

a thermosetting resin which has a very wide B stage. In the B stage it melts under heat and can later be made to solidify by polymerization. This property is used in the molding of slot portions of coils using shellac-coated paper spacers and molding mica V rings. Spirit varnishes and lacquers dry chiefly by evaporation of the solvent. Strictly speaking, varnishes are not solutions but are colloidal in nature; therefore, they present difficulties in filtration and clarification as well as in storage, being susceptible to temperature changes, humidity, contact with air, etc.

Air-drying varnishes are generally inferior to baking varnishes in most essential insulating properties. In spirit varnishes water is left in the film when the solvent evaporates. The gum may granulate, and the film is softer, holding small amounts of solvents for a considerable time. In addition, these "spirit" varnishes are practically useless as insulation, except in the role of stickers or binders for good insulating material, such as mica, treated paper, and cloth. In air-drying oil-gum varnishes, the very factor that causes their rapid hardening is ultimately the cause of failure. The driers, which are incorporated in the formula and produce rapid oxidation, do not stop the hardening at the best possible place but allow it to continue on until the film becomes brittle or weak. The same is true to a much less extent with the synthetic resin varnishes.

A drying oil is an extract from animal or fish fat or from a vegetable seed or nut. There are hundreds of such oils which bear a very close chemical resemblance, but most of them are glycerides, *i.e.*, a combination of glycerin with organic acids having high molecular weight and a long chain organic structure. These liquid glycerides are capable of taking up oxygen from the air and drying to a solid film by the double process of oxidation and polymerization. This last term can be defined simply as a process where the glyceride changes by union of two or more of its molecules into a compound having the same elements in the same proportions but also having a higher molecular weight and different physical properties. The heat and oxygen produce the larger complex chemical structures which thicken to form a gelatinous or resinous mass. The degree to which the glycerides oxidize and polymerize depends on the type and constitution of the organic acids present.

Of the hundreds of drying oils which have been isolated, there are just a few which have been important for centuries in varnish and enamel making. The chief drying oils used in insulating varnishes are linseed, perilla, and tung (chinawood) oils. Linseed oil is the most familiar and the oldest in history. It is derived from flaxseed by pressing or solvent extraction. Tung oil comes from a large nut resembling a huge horse chestnut, the fruit of the Chinese tung tree. Linseed oil is much slower drying than tung oil and imparts flexibility and life to films, whereas tung oil gives toughness and improved water and chemical resistance. It is most important that tung oil has the almost unique property of setting up rapidly to a gelatinous mass throughout a very thick layer or film. This is, of course, a very useful property for coil-treating varnishes. Less oxygen and heat are required for this change than with linseed oil. Soybean oil is a newcomer to the field of paints and varnishes and may be expected to become increasingly important in this field.

The rate of drying of an oil is, of course, connected with the amount of oxygen it can absorb, but it is not dependent upon

this factor alone. The rate also depends upon temperature, light, moisture conditions, and small quantities of accelerating catalysts, called driers. Driers are used with drying oils to accelerate the conversion of liquid to solid form. They are most important for air-drying varnishes, since they bring about the setting of the film within a reasonable number of hours rather than days. Driers are organic salts of metals, such as cobalt, manganese, and lead, which act as oxygen carriers or catalysts and greatly speed up the polymerization. Very small amounts (a few tenths or thousandths of a percent) are sufficient for maximum effect. Too much drier often impairs durability and life of the film or may act as a retarder rather than an accelerator. Besides the drying oils, there are also the semidrying and nondrying oils, in which this property of picking up oxygen and drying to a hard film is less marked or nearly absent. These oils, of which castor oil is an example, are used largely in finishes, where they act as plasticizers or flexibilizers for the film.

The natural resins, or "gums," now fast being superseded by synthetic materials, include shellac, rosin, Kauri, Manila, Congo copal, and many others, most of which are found in India or the East Indies. They are gums or pitches which exude from trees, bugs (in the case of shellac), or fossil accumulations which come from fossilized trees. Shellacs and copals, especially, are graded according to hardness and solubility, but they vary considerably in the amount of dirt and impurities they contain and from lot to lot in properties and workability. It was this lack of uniformity and difficulty of handling which gave synthetic or chemically prepared resins their chance.

Rosin is a product of pine pitch from which turpentine is also obtained. It is a hard, brittle resin which melts at 80 or 90 C. It has a wide range of application, but for varnishes its use alone is limited by its softness and lack of durability and its high acidity.

Ester gum, which stands midway between the natural and synthetic resins, is a product of the high-temperature reaction of rosin and glycerin. It is much less acid than rosin and more weather resistant and plastic.

In the last 25 years synthetic resin development has produced outstanding resins of several types which are replacing natural resins in most applications where quality, uniformity in composition and performance, and ease of manufacture are factors. The more important and successful types now in use are the phenol-formaldehyde type (of which Bakelite is perhaps the best known example) and the alkyd type. The chemistry of these resins is elaborate and complicated, but the simplest phenol-formaldehyde resins are made by combining a phenolic body, such as carbolic acid, with an aldehyde to form a hard resin. Proper choice of phenol and aldehyde gives a resin which can be blended, just as natural resins are, with drying oils. The simplest alkyd is a combination of glycerin with phthalic acid, but the more useful alkyd resins have drying oils combined chemically in the resin itself. Both of these type resins can be so formulated that application of heat causes a permanent hardening of the resin to an infusible state by the process known as heat polymerization.

Alkyd-type resins, especially those modified with drying oils, have developed during the past two decades into some of the most important synthetic raw materials for finishes and coating because of their outstanding gloss, adhesion, and durability. Especially important are the applications in metal priming and coating, outdoor

finishes, automotive and structural finishes, light-colored enamels, and printing inks. Until recently, applications of alkyd for insulation were limited by the electrical properties and moisture and heat resistance as well as through-curing properties. These properties have been improved markedly, and greater use is constantly being made of alkyds as insulating materials to replace the old black varnishes and compounds.

Melamine resins are a new group of high-grade thermosetting compounds. They are used in very much the same manner as phenolic resins for making laminates and molded compounds. In their final polymerized form, these resins are not soluble in water or alcohol and are highly resistant to most organic solvents. Melamines are useful in imparting hardness and toughness, as well as fast-drying properties, to other varnishes. During the war, submarine fires caused deaths which were attributed to the toxic fumes from phenolic resins. Glass-melamine laminates were substituted on both control apparatus and rotating electrical machinery on a large scale. Melamine resins are also used in combination with asbestos as well as cotton fabrics and paper to make laminates and molded parts. These products combine good arc resistance with tracking, moisture resistance, thermal stability, and low inflammability. It is expected that this type of resin and products employing it will become increasingly useful in the electrical industry.

Other important synthetic resins include the Amberols and Cumar, both similar to the phenolic type. There is a rapidly growing list of synthetic resins, some of which hold promise for future developments. The field is so large that it cannot be covered in this manual. Some of the newer resins may be of interest, however, and they will be briefly mentioned below.

The vinyl resins are derivatives of ethylene and acetylene, with strongly polymerizing characteristics. These polymers are becoming increasingly important in the plastics and coatings field, including that of synthetic rubbers and rubber substitutes. Most of these materials are thermoplastics, do not set up or cure with heat alone, and many are very tough and chemically resistant.

The simplest vinyl compounds are the alcohol, the chloride, and the acetate. Polyvinyl chloride is highly insoluble and flame resistant. Polyvinyl acetate is soluble in the proper solvents and thermoplastic. So-called copolymers of these have all manner of intermediate properties. These resins have wide uses, from adhesives and chemical-resistant coatings for food containers (Gelvas, Vinylites) to rubber substitutes and artificial silk (Vinyon, Koroseal).

If polyvinyl acetate is hydrolyzed and treated with formaldehyde, a very useful group of resins results. These resins are insoluble in most solvents and chemically quite inert as well as being very tough and strong. Formvar is one of a class of resins called polyvinyl acetals. As a film-forming material it has the disadvantages of nitrocellulose and cellulose acetate. Its solutions have high viscosity, adhesion is poor, and the thermoplastic film dries by solvent evaporation only.

Vinyon is a synthetic silk made from the copolymers of vinyl chloride and acetate similar in properties to nylon, which is a complex material more closely related to the alkyds in structure but having many similar properties to the vinyl polymers.

Silicone resins are a recent development and are applicable to class H insulation, where high thermal endurance is required.

The chemical nature and background are given in more detail in Sec. 2–14. These varnishes are available in a wide range of properties. It is theoretically possible to reproduce the general characteristics of all the organic varnish types in the silicone type of varnish. **Silicone resins have good electrical properties to supplement their outstanding thermal endurance.** Their physical properties are usually somewhat inferior to their organic resin counterparts. This is partly attributable to their slow cure except at very high temperatures. Intensive activity is under way for further development and evaluation of silicone resins and varnishes containing them. However, those now available commercially have many uses when applied with knowledge of their properties and limitations.

Silicone resins have been developed in two general classes. One is the insulating type which is comparable in most properties to the oleoresinous varnishes so long generally used for electrical insulation. There are two varieties of this class. The first such varnish requires baking temperatures sufficiently high (200 to 250 C) as to prohibit its use on organic materials such as paper, cotton, and silk, and it should be used only on inorganic materials such as glass fiber, asbestos, mica, or ceramics. The second variety, which was developed later, is comparable in general properties but dries to a tack-free condition at 150 C. Complete cure, by chemical reaction, required further baking at temperatures of 200 to 225 C, which improves its film hardness and strength at elevated temperatures. Both varieties are being used to treat glass-covered magnet wire, to coat fiber-glass cloth, and as a binder for building up flexible mica-glass-laminated sheet. They are also used as the final impregnating and coating varnish to bind together the individual machine components and waterproof the complete assembly. Another type of silicone resin corresponds in general behavior to the organic thermosetting resins normally used to make rigid laminated insulating parts. These thermosetting silicone resins are being used to bond fibrous glass and asbestos laminated structures and to bond special coils requiring hardness and rigidity.

A simple but significant property of all silicone compounds is their resistance to moisture. Silicone varnish films transmit moisture vapor at about the same rate as organic varnishes, but water does not easily wet silicone-resin-treated surfaces. Therefore, conducting films of moisture are far less likely to form than under similar atmospheric conditions on conventional organic-resin-treated surfaces. The importance of this characteristic is hard to evaluate in general terms, but it is apparently of considerable significance on shipboard electrical equipment.

For black varnishes, the asphalts or pitches play the same role as the resins do in the case of the clear varnishes and may be used together with resins. Among naturally occurring asphalts (which are mined, much as rock minerals, from veins) are gilsonite, a hard brittle, substantially pure asphalt, and various softer, more plastic materials, such as the famous lake of asphalt in Trinidad. Various pitches are also available. These are the end products of the distillation of petroleum, coal tar, wood, and various vegetable oils and fats, chief of which is stearin pitch.

The pitches vary greatly in solubility and melting point or flow point. Some may be modified to give increased elasticity and stability by blowing with hot air. Their stability in a varnish blend depends greatly upon the cooking and upon the thinner used.

The literature abounds with contradictory statements as to the value of asphaltic materials. They are susceptible to oxidation and are affected by light and heat, failure occurring by the progressive development of fine cracks. When the film is intact, the asphalts are excellent in acid and moisture repellance **but are very soluble in oils.** When added to clear varnishes, asphalts retard the drying considerably unless they are used in sufficient quantity to give additional hardness themselves.

The correct terminology for paints and varnishes has been outlined in Fig. 2-3. One outstanding exception to those definitions should be noted. Varnishes used for coating wire are usually called "wire enamels" though they contain no pigment. Oleoresinous varnishes have been used for years for coating magnet wire.

Synthetic resin enamels have been developed which are fast displacing the drying-oil varnish-type wire enamel. An important synthetic wire enamel is a polyvinyl acetate which is hydrolyzed and treated with formaldehyde to produce a class of resins called polyvinyl acetals. This resin is insoluble in most solvents and is chemically inert as well as being tough and strong. It has a high viscosity in solution form, and the thermoplastic film dries by solvent evaporation only. This type of resin when used as a wire enamel produces a very tough insulation which can withstand severe winding abuse. It also has the great advantages of relative freedom from heat shock and good thermal endurance for a class A material. It is less susceptible to softening by varnish solvents than are conventional varnishes.

2-12. INSULATING COMPOUNDS

Under this heading are listed solid, plastic, or semiliquid materials which contain little or no thinner. They may be resins, asphalts, waxes, or varnish bases or blends of these materials with or without fillers, such as talc, silica, quartz sand, mica dust, slate, asbestos, glass fibers, and whiting. They are generally classified as to their uses as sealing, filling, or treating compounds.

1. *Sealing and Filling Compounds.* Sealing and filling compounds are used for protection of windings and for filling cavities in metal, porcelain, and other materials to exclude moisture, dust, and dirt. They may be either solid compounds which are melted and poured in place, solidifying on cooling, or plastic or puttylike compounds such as are used in armature and field coils. These compounds gradually set to a firm condition, with or without heat, according to the particular compound. For filling cavities, etc., it is important that the shrinkage, especially at low temperatures, be as low as possible or as nearly as possible like that of the material with which the compound is in contact and that the adhesion be good and cracking eliminated. For sealing compounds used on windings, impact strength, thermal conductivity, and aging at elevated temperatures are also important requirements in certain applications.

2. *Treating Compounds.* Treating compounds find an extensive use in a solidified mass from which moisture and air are excluded. Coils from which all moisture has been exhausted by a vacuum process are filled with melted pitch compounds and rendered rigid and moistureproof. A compound for this application should be sufficiently tough to withstand rough handling and have a uniform flow point, a high degree of fluidity, and high penetration at the treating temperature.

2-13. PLASTICS

In a very broad sense plastics can be defined as nonmetallic materials that can be molded or extruded into sheets, tubes, rods, filaments, or complex forms. A more practical definition limits plastics to certain natural and synthetic resins that can be extruded, cast and molded and sometimes includes others used for coatings and thin films. Many plastics are based on the same organic resins that are used for varnishes for impregnating coils and surface-coating windings. The basic resins used in varnishes are covered more fully in Sec. 2-11. This section will be confined to those plastic materials which are used in sheet, rod, filament, and molded form. Many natural resins have been used in the plastics industry such as shellac, bituminous resins, rubber, and gutta-percha. The development of phenol formaldehyde in 1909 marked the beginning of the molded-plastics industry.

Plastics may be divided into two classes according to their physical conditions under heat. Resins which experience no chemical change when heated for molding are called "thermoplastic." They can be re-softened by heating again and again. Plastics which undergo a chemical change during the molding operation are called "thermosetting." These materials cannot be re-formed, and usually their form can be altered only by heating far above the molding temperature which destroys the resins.

Most plastic resins are not used in their pure state but are used in conjunction with fillers, which extend the resin so as to make the finished product more economical. Such fillers may be wood flour, cotton flock, rag fibers, chopped cloth, asbestos fibers, silica powder, and mica dust. In the special class of laminated plastics various cloths or papers are treated with resin and molded together in sheet form.

The basic resins frequently do not have the exact physical properties desired and are sometimes modified partially in order to make them softer or more flexible by the addition of plasticizers. These plasticizers act as lubricants between the molecular chains of the base resins. Plasticizers are usually less stable than the resins to which they are added and may disappear during aging, especially at elevated temperatures. Such fugitive plasticizers cause many of the so-called plastics to shrink and become brittle as the plasticizer disappears.

A few classes of plastics used in electrical insulation for machinery deserve special mention.

1. Polyamids are plastic compounds with a nitrogenous composition. These resins are crystalline in structure and are processed so as to line up the crystals in a long chain. This produces very strong fibers approaching the tensile strength of steel. The polyamids are largely used in the manufacture of filaments which are made into fabrics. Nylon is an excellent example of this class.

2. Polyacrylates are a wide family of resins ranging from viscous liquids to hard thermoplastic solids. The one most commonly known is methyl methacrylate, known commercially as Lucite and Plexiglas. The outstanding properties of the cast and molded forms are their excellent transparency, lightness, rigidity, and good weather resistance. These materials are used for molding complex shapes. Some of the softer resins are used as adhesives.

3. Polystyrene is a clear, hard, light thermoplastic. It is suitable for molding a variety of complex shapes for insulation purposes.

4. Polyvinyl resins include a broad group of resins which can be subdivided as acetals, alcohols, esters, and halides. These vinyl resins offer an exceptionally wide range of properties for many insulation applications. They are obtainable as viscous liquids and may be formed into flexible or rigid solids. They can be made to be quite flexible at ordinary and subzero temperatures, which has led to their use as rubber substitutes. Polyvinyl chloride is of interest in insulation, as it is used for making flexible tubing, gaskets, and extruded wire covering. It is unaffected by oils and has excellent chemical resistance and good electrical properties. A material of this kind is sold under the trade name of Koroseal. Acetate-chloride vinyl copolymers offer excellent properties for electrical insulation as well as many industrial uses such as waterproofing fabric and paper, lining food cans, and making filaments for fabrics. They are also molded into a variety of shapes for numerous applications.

5. There are many cellulose derivatives in the plastics family. Cellulose nitrate was the original plastic which was developed in 1869 as a substitute for ivory in billiard balls. It has toughness and water resistance but is highly inflammable and difficult to mold. Cellulose acetate has many advantages over cellulose nitrate, as it is noninflammable and easily molded. The material is used in transparent sheets, tubes, rods, and many standard shapes. Cellophane is regenerated cellulose and is frequently confused with cellulose acetate. It is used in film form for packaging and is sometimes employed for insulation purposes. Ethyl cellulose can also be fabricated into thin sheets and extruded into tubes as well as used for injection molding. In some forms it is quite rubberlike.

6. Inorganic molded compositions can be included under the broad definition of plastics. There are a number of cold-molded refractory compositions such as those made from portland cement filled with asbestos fibers as well as clays and silicates. Mycalex is the trade name for a glass-base plastic filled with powdered mica. It is molded under high pressure and temperature. It possesses good flexural strength and fair impact strength, has a hard, smooth finish, and will withstand temperatures up to 550 F.

7. Two types of fluorinated hydrocarbons are available which have high-temperature characteristics and are unique in being practically insoluble in all known solvents and reagents. Teflon is the trade name for polytetrafluoroethylene, reported to be good for temperatures in the range of 200 to 250 C for continuous operation. This material is available in extruded rods, films, and sheets, and a dispersion in water is available for coating purposes. Kel-F is the trade name for monochlorotrifluoroethylene, reported to be suitable for continuous operation at temperatures from 175 to 200 C. This material is available in rods, tubes, films, and sheets and can be molded in complex shapes. It should be recognized that the temperature ranges for both materials are tentative, as they are now undergoing more careful evaluation by industry and the armed services. Either material may be operated at somewhat higher temperatures, depending upon the duration of the temperature and the physical stress on it. The original form of the materials and manner of application or fabrication may also be important in establishing their thermal endurance limits.

2-14. SILICONE COMPOUNDS

The advent of organosilicon compounds was an important milestone in insulation

development. These materials, generally called "silicones," have outstanding thermal endurance and excellent moisture resistance. When silicone materials are used in combination with inorganic insulation components such as mica, asbestos, and fiber glass, the resultant composite materials have superior characteristics for electrical insulation. Thermal endurance and moisture-resistance properties are of special interest to Naval personnel.

Silicones are a new class of synthetic polymers which resulted from fundamental research in the field of chemistry, bounded by the glasses and silicates on one hand and by the organic plastics on the other. Silicone compounds are derived from sand, brine, coal, and oil as ultimate source materials. However, their manufacture involves a number of steps and a great deal of industrial and chemical technology. Silicone compounds are available in a wide variety of forms which include plastic resins, rubbers, oils, greases, and film-forming materials as well as high-temperature varnishes. Silicone compounds are similar in chemical structure to hydrocarbon compounds, and many of their physical characteristics are alike. Silicones are characterized by a chemical structure in which silicon takes the place of carbon in certain portions of the molecule. Silicone compounds can be said to be "semi-inorganic," as the backbone of the molecule is a silicon-to-oxygen linkage instead of the carbon-to-carbon linkage such as occurs in hydrocarbon compounds. It is probable that silicone compounds will be developed to be analogous to all the main varieties of hydrocarbons.

Before adopting silicone materials for use as electrical insulation, the electrical industry first subjected the basic materials to laboratory tests such as used for testing organic insulations. Tests on silicone resins, silicone-treated materials, and apparatus impregnated with silicone varnishes have demonstrated that:

1. An unusually high order of thermal endurance is obtained with silicone resins.
2. The composite insulating materials employing silicone compounds are usable with relatively minor variations in conventional processes (mainly in processing temperatures).
3. On some types of electric apparatus, an appreciable advantage may be obtained in rating through operating at the higher temperatures.
4. The moisture resistance of silicone insulating materials is outstanding, and there may be a field for its use where no advantage is taken of its high thermal stability.

It is important to recognize that the use of silicone resins in electrical insulation need not represent any radical departures from most well-established practices. Inorganic components of high-temperature insulation have long been available, and their characteristics proved. It was the organic bonds, impregnants, and surface treatments which limited the thermal endurance of composite insulation containing mica, asbestos, and fibrous glass. **There is ample evidence that silicone resins used with these well-known inorganic materials provide a new class of high-temperature insulation.**

Silicone rubber is an important new variety of high-temperature insulation in the organosilicon family. It is available in a number of forms with varying degrees of hardness and toughness. Silicone rubber pastes are useful for filling voids around leads in motors and generators. Silicone-rubber-insulated wire and cable provide a class H lead insulation capable of withstanding high operating temperatures as

well as high baking temperatures required for treating coils with silicone varnishes. Silicone rubber is used for coating glass fabrics which are useful as insulation in many applications. Unsupported silicone rubber may be applied by taping on coils. Silicone rubber may be molded onto a variety of shapes and sizes requiring high-temperature insulation. Silicone rubbers have excellent dielectric properties, including high dielectric strength and low dielectric loss. Some kinds have high thermal conductivity, which aids in the dissipation of heat. Physical properties of silicone rubber are not affected seriously by extremely low temperatures, as the brittle points of many of these compounds are less than minus 70 F. Silicone rubber can be handled with relative ease and cured at reasonable temperatures (about 135 C). Unlike most resinous insulations, silicone rubber does not become progressively more brittle in continued service at high temperature.

2–15. SOLVENTS

A varnish solvent can be defined as a liquid by which a resin or gum can be brought into a fluid state or the viscosity of a drying oil can be reduced. Though not insulation in themselves, solvents are an important part of many insulating processes. The general purpose of solvents in varnishes is to move solid resins or gums from one place to another, particularly where it is desired to deposit them in thin uniform films. The term "thinner" is sometimes confused with solvent. A thinner, or diluent, is a liquid used to thin, or dilute, a solution. It may or may not be a true solvent (when used alone) of the solid in the solution. Thinners are generally used to dilute varnishes to a suitable viscosity and specific gravity for application. Frequently the original solvent is used as a thinner, though not always (see Sec. 5–42 for Navy-approved solvents for use as thinners).

Solvents are only part of the varnish during the application process. Therefore, the same solvent may be used in both organic and silicone varnishes. The most important characteristics of solvents can be summarized as follows:

1. Solvency power.
2. Volatility.
3. Toxicity.
4. Inflammability.
5. Stability.
6. Specific gravity.
7. Refractive index.
8. Acidity.

Many of these characteristics are merely identity tests and have little to do with the actual performance of the solvent or thinner. However, some of these require amplification.

1. *Solvency Power.* Liquids which possess the highest solvency power yield solutions of the lowest viscosity. The viscosity of a solution is a true measure of the solvency power of the solvent. The solvent producing the lowest viscosity (for a given resin-to-solvent ratio) has the greatest solvency power. Actual measures of solvency power include the Kauri-Butanol number and the aniline point.

2. *Volatility.* The volatility of a solvent is measured by its vapor pressure and the rate of evaporation. Nearly all substances give off vapor and therefore exert a vapor pressure. Solvents of varnishes evaporate rather freely at room conditions as can be determined from their odor. The boiling range is an important test of the volatility of a solvent as well as an identity check.

3. *Toxicity.* The toxicity of a solvent is an important consideration in its selection.

This requires medical evaluation, and it is important that solvents used in closed spaces not be seriously harmful to the human system.

4. *Inflammability.* Inflammability is usually measured by the flash point, which is merely the temperature at which a flash will occur on the surface of a cup when a flame is passed over the fluid. This is an excellent indication of the hazard of using a particular type of solvent.

2–16. ELECTRICAL INSULATION DEFINITIONS

The basic kinds of insulating materials have been reviewed in earlier sections. The remainder of Chap. 2 defines and describes the fabricated forms of insulation employing these basic kinds of insulation components. The fabricated electrical insulations as applicable to shipboard machinery are defined by the Navy as follows:

1. *Insulation, Electrical, Sheet.* An electrical insulation item consisting of (*a*) condensed fibers, natural or synthetic, in sheet form such as paper, fiber, or glass (usually short fibers); (*b*) natural or synthetic rubber with or without reinforcement; or (*c*) a reinforced flat, laminated (plastic) composite structure.

2. *Insulation, Electrical, Cloth.* An electrical insulation item consisting of woven fabric of natural or synthetic fibers such as cotton, silk, rayon, glass, asbestos, or nylon, usually in widths of over 8 inches. It may be plain, impregnated, or varnished.

3. *Insulation, Electrical, Tape.* An electrical insulation item consisting of tape of any kind but usually consisting of woven fabric (less than 8 inches wide), slit film, or sheet material. Tape may be plain, impregnated, or varnished.

4. *Insulation, Electrical, Cordage.* An electrical insulation item consisting of (*a*) a twisted yarn of organic or inorganic fibers or (*b*) an extruded synthetic plastic flexible rod, usually less than ⅛ inch in diameter.

5. *Insulation, Electrical, Thin Film.* An electrical insulation item consisting of a nonreinforced synthetic plastic extrusion or shaved thin film usually less than 1⁄16 inch thick and wider than 8 inches.

6. *Insulation, Electrical, Mica.* An electrical insulation item consisting of natural or synthetic mica in the form of blocks or splittings. When pasted or built up with binders and reinforcement, the composite mica structure should be classified as Insulation, sheet, tape, or tubing.

7. *Insulation, Electrical, Tubing (and Sleeving).* An electrical insulation item consisting of (*a*) a hollow cylindrical plastic extrusion, (*b*) a round woven fabric, (*c*) a mandrel or bar wound plastic in built-up layers, or (*d*) a material compressed or formed into tubing. It is usually circular but may be square or other shape.

8. *Insulation, Electrical, Rod.* An electrical insulation item consisting of a solid bar, usually circular and long in proportion to its breadth and thickness.

9. *Insulation, Electrical, Mat.* An electrical insulation item consisting of a fibrous or matted form of somewhat open construction laid down in a random pattern. It may be plain or impregnated.

10. *Insulation, Electrical, Sliver.* An electrical insulation item consisting of bulk fibers of any type.

11. *Insulation, Electrical, Liquid Dielectric.* An electrical insulation item consisting of a natural or synthetic resinous substance in liquid form having dielectric properties.

12. *Insulation, Electrical, Compound.* An electrical insulation item consisting of a natural or synthetic resinous substance in

puttylike form having dielectric properties.

13. *Insulation, Electrical, Molding (Compound)*. An electrical insulation item consisting of a bulk mixture of plastic resinous materials with or without reinforcement capable of being formed by pressure and/or heat into a definite shape, also the molded article.

14. *Insulation, Electrical, Formed.* An electrical insulation item consisting of a sheet material formed into a simple shape such as a U-shaped wedge, an angle, or a V-shaped part usually by the application of pressure and/or heat.

2–17. OBJECTIVES OF MATERIAL SPECIFICATIONS AND STANDARDS

Numerous standards exist which specify insulation material characteristics. This discussion will relate to industry standards established by engineering associations and trade associations as well as Navy specifications and specifications by other branches of the Federal government such as Joint Army-Navy specifications and Federal specifications.

Many manufacturers' standards define insulation requirements and classify materials as to the applications. They also establish limits for the control of the uniform quality for the various classes, types, and varieties of materials. Navy standards have a twofold purpose: (1) They establish performance standards for materials which are interpreted with respect to the end use of the material. They are equally applicable to materials purchased by the Navy and to materials which are component parts of complete apparatus purchased by the Navy. (2) They establish identity standards for materials and limits of physical sizes. These identity and size specifications apply only to those materials purchased as such by the Navy, as these characteristics are usually of no consequence when they are component parts of complete apparatus furnished to the Navy. **It is the performance characteristics which must be met on complete apparatus.**

The performance values specified in the applicable Navy, Federal, or Military specifications for various types and classes of electrical insulation are based upon the minimum characteristics. These specifications for insulating materials cover certain features which, though essential from the standpoint of stocks, need not apply to the manufacturers of Naval electrical equipment in the utilization of the same types and classes of materials. For example, such features as the thickness, length, and width of sheet or tape insulation; the dimensions of rods, tubes, and shapes of molded or pressed insulation; and the flash point, drying or baking time, working viscosity, etc., of liquid or plastic insulation are essential features when direct purchases of insulation are made, but they are not of consequence when the same materials are applied by the equipment manufacturer. Thus in the application of the Naval specifications (Navy, Federal, Military) to manufacturers' designs, only the performance values (insulation resistance, dielectric strength, heat resistance, moisture absorption, aging, tensile, flexural and compressive strength, etc.) need be considered.

The quality of the insulation material used in the construction of the electrical equipment should be at least equal to that covered by the Naval material specifications. Where materials are proposed to be used which are not in accordance with specifications, it must be clearly demonstrated that an improvement in operating characteristics or a saving in weight without sacrifice in reliability of the equipment can

be accomplished thereby and that such substitutions do not preclude the subsequent use of standard material in effecting repairs or replacements by Naval activities. The use of materials not in accordance with Naval specifications will be permitted if satisfactory to the bureau or agency concerned. **In all cases equipment manufacturers should reference the standard Navy material specification on their equipment plans so that in the repair of this equipment by Naval activities, the correct insulation may be provided from stock.**

2-20. ORGANIC FIBROUS INSULATING MATERIALS

Organic fibrous insulating materials can be divided into two groups. The first group consists of the natural fibers such as cotton, linen, and silk. Cotton is a soft, white, almost pure cellulose fiber, which varies in diameter from 0.63 to 0.84 mil. Linen is a somewhat coarser fiber, derived from the flax plant, as the fibers average from 2 to 25 mils in diameter and frequently are 18 inches long or more. Silk is the thread from the silkworm cocoon and has individual fiber diameters ranging from 0.5 to 1 mil. All these natural fibers are spun into threads which are used for a variety of insulating purposes. Cotton and silk threads are widely used as wire covering as well as for weaving into cloths, tape, and tubing. Linen is not widely used for electrical insulation. **All these natural fibers have relatively low thermal endurance, being class O when untreated and class A when varnish-treated.** They are all sensitive to moisture and generally require treatment to develop an acceptable level of insulation properties.

The second group of organic fibrous insulating materials are the synthetic monofilament types such as rayon and nylon. These fibers are essentially plastic materials spun into continuous lengths of monofilaments which can be fabricated into textiles in very much the same manner as the natural silk fibers. **These synthetic fibrous insulating materials are all class O or class A insulation depending upon whether they are treated or not.** However, there is considerable difference between different resins as to moisture-absorption and thermal-endurance properties.

2-21. ORGANIC NONFIBROUS INSULATION MATERIALS

Rubber is made from the milky sap (latex) of a tropical tree originally a native of Brazil but later cultivated in eastern Asia. Latex is a suspension of the rubber globules in a water emulsion. Crude rubber is prepared by coagulation of the latex and by drying to evaporate the water. The raw rubber is converted into the rubber of commerce by vulcanization, which is carried out by heating the crude rubber with sulphur and sometimes with accelerators. The vulcanized rubber then attains its properties of elasticity, tensile strength, durability, resistance to moisture and solvents, and insensitivity to moderate temperature changes. Rubber compounds contain other materials besides sulphur to impart the desired characteristics. Many other materials are added as fillers in order to obtain the desired characteristics for the particular rubber compounds. Typical fillers include whiting, zinc oxide, clay, barytes, magnesium carbonate, gas carbon, lampblack, carbon black, talc, chalk, and sometimes organic materials such as ozokerite, paraffin, pitch, waxes, bituminous rubber substitutes, and certain vulcanized vegetable oils.

There are many rubberlike materials known as synthetic rubbers and elastomers. These include the following:

1. Buna S is a copolymer of butadiene and styrene. It is rubbery and does not soften much with heat. It vulcanizes with sulphur to give nonthermoplastic characteristics. It is very rubbery, with high tensile strength and good elongation at break. It recovers rapidly after stretching, as it has excellent rebound elasticity. It is resistant to abrasion and is fairly resistant to heat.

2. Butyl is made from petroleum by copolymerization of isobutylene with small amounts of butadiene or isoprene with suitable catalysts. It polymerizes to form a solid rubbery compound. It has good physical strength and electrical properties. It is affected by oil and solvents about the same way that natural rubber is. It has good thermal stability and excellent abrasion resistance.

3. Perbunan is a copolymer of butadiene and acrylonitrile. It is rubbery and does not soften much with heat. It vulcanizes with sulphur to become nonthermoplastic. It has high tensile strength and good elongation at break with fair rebound elasticity. It is resistant to abrasion. It swells very slightly when exposed to oil, but most properties are not deteriorated by oil.

4. Neoprene is a linear polymer of chloroprene. It is stiff and slightly rubbery and softens greatly with heat. It vulcanizes by heat to become nonthermoplastic. It has high tensile strength, good elongation at break, and fair rebound elasticity. It is very resistant to oil, and its properties are not deteriorated by oil. It resists corona, ozone, and sunlight.

5. A linear polymer of isobutylene is available under the trade name of Vistanex. It is rubbery, and while it softens at high temperature, it does not harden at low temperatures. It is colorless, odorless, and inert chemically. It cannot be vulcanized.

6. A rubbery condensation product of organic aliphatic dihalide and alkaline polysulfide is sold under the trade name Thiokol. It is slightly rubbery and softens with heat. It vulcanizes by action of heat and metallic oxides to give a somewhat rubbery product still slightly plastic. It has fair tensile strength and fair elongation at break. It is very resistant to oil and aromatic solvents and resists corona, ozone, and light.

7. Plasticized gamma polyvinyl chloride products are widely used. One variety is sold under the trade name of Koroseal. It possesses a great range of rubbery characteristics and is plastic at high temperature. It is colorless, odorless, and resistant to chemicals and oils. It cannot be vulcanized. It is resistant to ozone, acids, and oils.

8. Gutta-percha or balata is a linear polymer of isoprene (an isomer of natural rubber). It is tough and horny, becoming rubbery at higher temperatures, finally melting. It possesses good electrical properties. It can be toughened by vulcanizing with sulphur, becoming nonthermoplastic. It is tough, slightly rubbery and has good strength with high elasticity.

9. Silicone rubber is a polymer of the silicone oils filled with one of several varieties of finely powdered loading compounds. These rubbery materials have outstanding thermal endurance like all silicones and possess very good electrical properties. The early varieties were somewhat weak mechanically, but recent developments have greatly improved the physical properties.

2-22. INORGANIC FIBROUS INSULATING MATERIALS

There are two varieties of inorganic fibrous insulating materials. The older

form is asbestos, which is fabricated into paper, cloth, and tape but frequently requires the addition of small percentages of organic fibers. Fiber glass, although a recently developed material, is woven into all forms of fabrics without the addition of organic fibers.

Asbestos Insulation Products. Asbestos fabrics are not affected by transformer oil or the ordinary oils. Strong mineral acids will dissolve the asbestos. Strong alkalies of the alkaline-earth type will not affect the asbestos. The electrical resistance is greatly reduced by moisture, and asbestos must be in as dry a condition as possible when used as electrical insulation. Asbestos fabrics are poor electrical insulation and should be varnish-treated when used as such.

Asbestos paper is obtainable in rolls up to and including 1/16 inch thickness and, being made of chrysotile asbestos, may contain a considerable number of magnetic oxide of iron particles. Some forms are processed to remove most of these magnetic particles. Asbestos paper can be readily formed. It contains appreciable percentages of wood pulp and glue for strength. It is flexible and can be bent flat back upon itself without breaking. Applications include insulation where heat- or arc-resisting material is required, wire covering, and turn insulation for strap field coils.

Asbestos cloth made of Canadian chrysotile asbestos is used for general insulation applications. It consists of approximately 13 to 20 percent cotton. Applications include laminates and hoods over armature bands or end windings.

Asbestos-fabric tapes are used in thicknesses of 0.010, 0.015, and 0.025 inch. The 0.010-inch tape has a smoother finish than the other thicknesses. It is constructed of asbestos warp threads containing approximately 15 percent cotton and fine cotton filler threads. The total cotton content of this type is approximately 30 percent. The 0.015- and 0.025-inch thicknesses are constructed of asbestos warp and filler threads, and the cotton content is approximately 15 percent, but a maximum of 20 percent is generally permissible. In certain applications where high electrical stresses are encountered, the low resistivity of the tape may be objectionable. Tapes 0.015 and 0.025 inch thick will withstand 300 C indefinitely except that the cotton will burn out leaving the asbestos fibers intact. In case of 0.010-inch tape the cotton filling threads and the cotton in the warp threads will burn out when heated to 300 C. The cotton contained in the tape will deteriorate rapidly at 100 to 120 C even when oxygen is excluded.

Asbestos twine is made of 100 percent Canadian chrysotile asbestos. When sized with starch, it has a smooth surface.

Asbestos millboard is made up of plied sheets of asbestos paper. It is stiffer than the paper and breaks on being bent. Applications are insulation where heat- or arc-resisting material is required.

Glass Fiber. Fiber glass is truly glass in fibrous form and as such retains most of the characteristics commonly associated with glass. Because of its form, fibers finer than human hair, it gains several desirable characteristics that make it an unsurpassed insulating material when properly impregnated. These glass fibers are twisted into yarns and tying cords, and the yarns are woven into tapes and cloths and braided into sleevings. In textile form, fiber glass provides a thin, strong, flexible fabric base for supporting insulating varnish films.

The nomenclature for fiber-glass textiles is of interest. The first letter indicates glass composition by type (E for electrical); the second letter, C or S, the character of the

fiber (either continuous filament or staple fiber); the third letter, D, E, F, or G, indicates diameter of individual fiber. For example, E plus C plus D (ECD) designates glass of type E produced as continuous filament (C) of 0.00023 inch (D) average fiber diameter. Other average-diameter letter designations are:

E = 0.00028 inch
F = 0.00033 inch
G = 0.00038 inch

These are nominal fiber diameters and are subject to manufacturing tolerances. "Count or number" (following the three letters explained above) represents 1/100 of the yardage of raw glass fiber per pound. Plies in continuous-filament yarns are designated by two digits following the count number. The first digit shows the number of original strands twisted; the second, the number of these yarns plied. The total number of strands is the product of both numbers (except 0 is multiplied as 1). Plies in staple fiber yarns are designated by number following those indicating yards per pound. "Yards per pound" values vary slightly owing to manufacturing limitations. The method of determining approximate yards per pound follows:

Continuous Filament. Multiply first number by 100; divide by number of strands. For example, ECD 450–2/2 has a nominal yardage of 45,000 yards per pound of single strand (450 × 100) and is made up of four strands (two plies each consisting of two strands twisted together before plying). Its average yardage is 45,000 ÷ 4 = 11,250.

Staple Fiber. Approximate yardage of yarns is count multiplied by 100. Examples: ESE 12.5/1 yarn contains 1,250 yards per pound. ESE 10/2 (two-ply yarn) contains 10 × 100 = 1,000 yards per pound, in singles divided by 2 = 500 yards per pound for the two-ply yarns.

2–23. INORGANIC NONFIBROUS INSULATION MATERIALS

Natural Mica Products. Built-up mica plate was first made in India in 1892. The process was very similar to the hand-laying method still used. It consists of laying successive overlapping layers of mica splittings or films of about 0.001 inch thickness and sprinkling each layer with a binding material. In early practice, all mica plate was built by hand, but increased demand required the development of rapid mechanical methods of laying the mica flakes. The underlying principle of most of the mechanical laying devices entails the use of so-called "snowing towers." One method employs a table 3 to 4 feet wide and 50 to 75 feet long. An endless woven wire screen belt passes over this table but remains stationary during the initial laying process. Laying is done by an electrically driven traveling snowing tower, which passes back and forth over the table and showers the mica flakes onto the belt. The carriage is fitted with a tank which feeds streams of binder over the successive layers and also with a roller which presses the binder in between the films. After the plate has been built up to the desired thickness, the belt is set in motion and carries the plate under a heavy knife that cuts off successive sections. These sections are placed on trays in vacuum ovens to remove the solvent and are then ready for pressing. Another method of building mica plate employs a stationary snowing tower and a continuously moving belt. The mica is "snowed" down a tower onto the belt, which passes under a sprinkler where the binder is applied. The material is then carried through a circulating oven to remove the binder solvent. Mechanical

shears cut the plate into sections as it comes off the belt ready for hot pressing.

One of the most important uses of mica plate is commutator segment insulation. Most varieties of commutator plate are machine built and composed of the smallest grades of white or amber mica and either orange shellac or synthetic resin binder. The different grades are various combinations of white or amber mica with the different binders present in varying amounts. The best grades of commutator plate are compression-tested to maintain seasoning characteristics within specified limits. A standard commutator plate is described in NEMA standards as having a maximum of 6 percent binder. However, some manufacturers control to 5 percent maximum, since an excess of binder resin may cause skidding or squirting of the segments in seasoning, resulting in a rough commutator.

Most of the molding plate is machine built, although for some applications, such as thin-wall molded cells, small motor V rings, and some high-voltage V rings, hand-built molding plate is used. Much molding plate is bonded with button-lac. Synthetic binders have been used, but such molding plate does not "form" so well as shellac-bonded plate. A binder for molding plate must be a thermosetting resin which has a B stage (in which the binder is thermoplastic) sufficiently long to permit forming and molding. In the thermoplastic state the resin must have good adhesion but low resistance to slippage in order to permit the mica flakes to slide over each other when the plate is formed. Shellac inherently contains 3 to 5 percent wax, which serves as a sort of lubricant, promoting the interfacial slippage during molding. Most molding micas contain 8 to 10 percent binder. A larger proportion of bond is required here than in segment plate mica to facilitate easy molding.

Hand-built plate requires even greater amounts of binder—up to 24 percent. The larger splittings used in hand building present larger unit surfaces and consequently greater resistance to slip. One grade of machine-built molding plate contains 16 to 18 percent of binder for production-mold V rings, where rapid forming is required. While V rings account for most molding mica, considerable quantities are used for channels, bushings, tubing, washers, and other miscellaneous parts.

Molding mica plate contains binder which is in the B stage. Heating the material (110 to 140 C is satisfactory for shellac) softens the resin binder, making the sheet sufficiently flexible for forming. It is necessary to cool the plate under pressure to produce good consolidation and adhesion. If it is desired to cure the formed piece (polymerize the bond so that subsequent heating will not cause softening), the piece must be baked under pressure. If a cured bond is broken, as in delamination of a bushing or V ring, it cannot be rebonded by reheating under pressure.

Machine-built flexible mica is built by the same methods as described for commutator and molding plate. The essential difference is in the binder, which must be a permanent thermoplastic at room temperatures. This gives a sheet with a somewhat leathery feel that is capable of being cold-formed. The finished flexible plates cannot be machined. Nonuniformities in thickness are corrected by hand patching.

The materials mentioned thus far are those which are built mechanically and account for about 80 percent of the raw mica used. Hand building, which was the first method employed, is used in manufacturing the best grades of insulating mate-

rials requiring high dielectric strength and uniform thickness. This method simply involves placing a layer of mica splittings so that the edges overlap ¼ to ½ inch. If the material is to comprise only one layer, it must be laid on a backing material which has been treated with a binder that will hold the splittings in place. If two or more layers are desired, the flakes may be laid on waxed paper and each layer covered with a coat or binder until the desired thickness is obtained.

The hand-laying method is employed largely on mica tape. Mica tape is built on a conveyor-type machine, usually 18 inches wide. The backing, or reinforcing, material is fed onto the conveyor belt and passed under a roller which coats the material with a binder. The required layers of splittings are then laid, each layer being followed by an application of binder. When the desired thickness is obtained, the top covering material is fed onto the assembly. Since the conveyor belt travels at relatively fast speeds, some portion of the bond solvent remains at this stage. To dry the material further, it is usually passed over heated rolls before being rolled onto drums. In some cases further drying is obtained by placing it in a vacuum oven for 24 hours. The material is then slit into tape of the desired width. Many varieties of tape are manufactured as well as varying widths and thicknesses for each variety. These materials differ with respect to the materials used in combination with the mica. Some tapes are comprised of one or two layers of mica covered on both sides with paper. This paper is a 1-mil rope or rice paper. Both the rope paper and the rice paper (sometimes called Jap paper) are especially adapted to this use. They both have the required high wet strength and low porosity. This tape is used for strand insulation applied either by hand or by machine and for general taping of coils. Other tapes are backed with starched cambric or fiber-glass cloth. These are similar to the paper-backed tapes except for their greater strength. One important tape is a silicone-mica-glass combination for high-temperature coil taping. Silicone-treated glass and silicone-resin-treated paper are used for backing or covering materials. The bond used is a silicone resin. There are also silicone-mica-glass combinations which have silicone-treated glass on both sides of mica bonded with silicone resins.

An important class of mica products is mica coil wrappers and slot cells. All these materials are built by the hand-laying process. They may be built in continuous sheets on a conveyor belt or on stationary tables. They constitute a class of high-quality insulation, most of them being dielectrically tested in the range of 3,000 to 5,000 volts. Wrapper and slot cells composed of one or more layers of mica are generally covered on one or both sides with a structural supporting fabric, paper, or film material. The resin bonds used for wrappers are tacky and plastic, being similar to those bonds used for the tapes. These materials are generally thicker than the mica tapes, ranging from 8 to 25 mils. Those which are built on conveyors are usually 36 inches wide, while those built on tables may be made to any convenient sheet size.

Mica Substitutes. Mica is employed in electric machinery because of its outstanding characteristics in three fields, namely, electrical, physical, and thermal. No other material has identical or equivalent properties in all three respects. Therefore, there is no universal mica substitute, and the substitute selected must be considered only as a replacement for a specific composite

mica structure for a particular application. It must be recognized that there is, as yet, no real substitute for mica itself but there are some substitutes for mica products for specific uses. The Navy Department in collaboration with the other armed services has sponsored a synthetic-mica-development program. Active work at the Colorado School of Mines has been in progress for several years, and more recently a great deal of work has been under way at the Electrotechnical Laboratory of the U.S. Bureau of Mines. The synthetic mica made under this program shows great promise, but it as yet has not reached the commercially usable state. In the present state of development the crystals are intergrown and the cleavage planes are too small to permit obtaining usable splittings. Beyond that lies the problem of developing industrial facilities for splitting synthetic mica when it becomes a reality.

2-24. LAMINATED THERMOSETTING INSULATION MATERIALS

Laminated thermosetting products consist essentially of fibrous sheet materials such as cellulose paper, asbestos paper, cotton fabric, asbestos fabric, and glass fabric, impregnated or coated with a thermosetting resin binder and consolidated under high temperature and pressure into hard, solid products of high mechanical strength.

The principal resins used in laminated thermosetting products are the phenolics. These are made by the chemical combination and partial polymerization of formaldehyde and phenolic bodies, such as phenols, cresols, or cresylic acid, under carefully controlled conditions. Other thermosetting resins include the melamines and the ureas. These are made by the chemical combination and partial polymerization of formaldehyde with melamine and with urea or urea derivatives or combinations. Copolymers of two or more of these resins may also be used. Silicone resins are also used in recently developed high-temperature laminates. The resins are dissolved in alcohol, alcohol-water, or other suitable solvents to form varnish solutions with which the fibrous sheet materials may be impregnated or coated.

After impregnation and drying, the material is cut into sheets which are stacked together between metal pressing plates and pressed under high temperatures and pressures to form laminated thermosetting sheets. During this operation the resin is transformed from a fusible soluble stage into one which is practically infusible and insoluble. Temperatures in the neighborhood of 270 to 350 F (approximately 132 to 180 C) and molding pressures of approximately 1,000 to 2,500 pounds per square inch are commonly employed. With certain resins and certain types of fibrous sheet materials it may be possible to produce satisfactory laminated sheets at much lower pressures. When the material has been heated for a sufficient period to bring about this change of state, so-called "thermosetting," the presses are cooled and the finished sheets removed.

The tubes are formed by rolling the impregnated sheet material upon mandrels between heated pressure rolls and then either oven-baking or pressing in a heated mold to complete the curing or setting of the resin into the infusible form.

Molded rods are composed of laminations of impregnated sheet material molded in cylindrical molds under high temperature and pressure and then ground to size.

Rods machined from sheets are also available. In these rods, the laminations are parallel chords of a circular cross sec-

tion. In general, the properties conform to the grade of sheet stock from which they are cut. This type of rod is low in flexural strength when stress is applied perpendicular to the lamination.

Molded shapes are composed of impregnated sheet materials cut into various sizes and shapes to fit the contours of a mold and molded under heat and pressure. In special cases some macerated material is used in combination with impregnated sheet materials, depending upon the design of the piece. The requirements of sheet specifications, particularly with regard to mechanical properties, cannot be considered as applying to molded shapes, except for rectangular and square tubes, since such properties will depend to a considerable extent upon the design of the piece.

While the properties of laminated thermosetting materials can be varied within quite a large range by variations in the sheet fillers, the binders, or manufacturing processes, it has been found that the major portion of the applications can be taken care of by a reasonable number of standard grades or classes.

Laminated phenolic is one of the strongest materials considered on the basis of strength-weight ratio. With a density for cellulose-base grades of approximately 1.35, only half that of aluminum, the mechanical grades find large application in the aircraft and other structural fields. The high strength, excellent resistance to moisture and heat, and good electrical properties of laminated phenolic, combined with the fact that it is readily machined, account for its large volume use in all branches of the electrical industry, **however, the poor arc resistance and high burning rate preclude the use of laminated phenolic materials for most shipboard electrical-equipment applications.**

The resistance of laminated phenolic to corrosion makes it suitable for many applications in the various chemical industries, particularly where organic solvents, organic acids in any concentration, or dilute inorganic acids are encountered. Laminated phenolic is not suitable in general for use in alkaline media, although certain grades are more resistant to alkalies than others and are used for special applications in dilute alkaline solutions.

The glass-base melamine laminated materials in the form of sheets, rods, and tubes are used primarily for the properties of arc and flame resistance, high mechanical strength, and great thermal endurance. Glass melamine laminates are used for most shipboard electrical-equipment applications in lieu of the laminated phenolic materials. The glass-base silicone laminates are used because of their great thermal endurance, resistance to arcing, retention of electrical properties under wet conditions, and lack of toxic concentrations of volatiles under extreme thermal conditions.

2–29. AVAILABLE FORMS OF ELECTRICAL INSULATION

The foregoing sections have reviewed the basic varieties of insulations and described their general characteristics. The remainder of this chapter is confined to enumerating the commercially available forms of electrical insulating products employed in electrical equipment as used by the U.S. Navy.

Navy stock sizes, grades, and types for all the following insulating materials are contained in Appendix I. Properties of these materials are given in Appendix II.

2–30. SHEET–FORM INSULATION

The form in which insulation is available has an important bearing on its use. Sheet-

form insulation is the most economical to manufacture and apply but is limited in application to simple shapes of coils and winding barriers. Sheet-form insulations are made from such basic insulating materials as papers, pressboard, fibre, mica, and laminated cloths and laminated papers.

2–31. *Insulation, Electrical, Paper* (*Slot Cell*), JAN–I–695, *Insulation Class O*

The types of papers include:

Type F, fish paper.

Type R, 100 percent rag paper, not chemically treated.

Type FP, one layer of fish paper sandwiched between cover films of synthetic resinous material.

Type RP, one layer of type R paper sandwiched between cover films of synthetic resinous material.

Type FC, one layer of fish paper laminated with one layer of varnished cambric.

Form S, sheets (except type F in nominal thicknesses less than 0.020 inch).

Form R, rolls (type F in nominal thicknesses less than 0.020 inch only).

The papers covered have the following characteristics:

Type F, fish paper, is essentially tough, strong, dense paper made from mechanically treated cotton rag stock which must be thoroughly washed to remove all chemicals that would cause deterioration.

Type R paper is extremely tough, strong, dense paper made from 100 percent selected rag stock not chemically treated. Both of these materials are used for slot cells and backing of other types of insulation where physical strength is important.

2–32. *Insulation, Electrical, Paper, Pressboard*, JAN–I–545, *Insulation Class O*

Pressboard insulation contains strong fibers. The greater portion of the material is made from cotton and linen fibers in the form of rags and not "broke" or waste paper. The board is made by the wet process with no pasteboard or similar material used. The board is made entirely of cotton or linen rag stock and contains not more than 5 percent jute or 5 percent ground wood. The material is suitable for blanking, punching, and molding into various shapes.

2–33. *Fibre, Insulating*, JAN–F–1148, *Insulation Class O*

Grades. Insulating fibre covered by this specification is divided into the following grades:

Grade BH, bone hard

Grade CH, commercial hard stock

Forms. The forms are as follows:

Form R, rods

Form S, sheets

Form T, tubes

Colors. The colors of each of the grades are as follows:

Grade BH, gray or natural color

Grade CH, gray or natural color, black, red

2–34. *Paper-base Laminates*, MIL–P–3115 (*Ships*), *Insulation Class A*

Materials covered by this specification are made from selected cotton rag stock paper and phenolic resins. They are suitable primarily for electrical insulating purposes wherein good electrical characteristics are required. They are weaker mechanically than the fabric-base grades and have poor fire and arc resistance.

PBG (*Commercial Grade XX*). For general-purpose electrical applications.

PBE (*Commercial Grade XXX*). Electrical grade with minimum cold-flow characteristics. Suitable for high-frequency and high-humidity applications.

PBE–P (*Commercial Grade XXXP*). Best electrical grade for high-frequency applications. A punching stock.

2–35. *Fabric-base Laminates*, MIL–P–3114 (*Ships*), *Insulation Class A*

Materials covered by this specification are made from selected cotton fabrics and phenolic resins. They are suitable primarily for electrical insulating purposes wherein fair electrical properties are required. They are stronger mechanically than the paper-base grades and have poor fire and arc resistance. The heavier the fabric base used, the higher will be the impact strength but the rougher the machined edge; consequently, there may be several subgrades in this class adapted for various sizes of gears and types of mechanical service. Should not be used for electrical applications except for low voltages.

FBG (*Commercial Grade CE*). Made of same fabric weight and thread-count limits as FBM (grade C). For electrical applications requiring greater toughness than PBG (grade XX) or mechanical applications requiring greater resistance to moisture than FBM (grade C). It is exceptionally good in moisture resistance.

FBI (*Commercial Grade L*). Made throughout from cotton fabric weighing 4 ounces or less per square yard. As determined by inspection of the laminated plate, the minimum thread count per inch in any ply is 72 in the filler direction and 140 total in both warp and filler directions. For purposes of identification, the surface sheets have a minimum thread count of 80 threads per inch in each of the warp and filler directions. This grade is suitable for fine machining applications, particularly in thicknesses under ½ inch. Not quite so tough as FBM (grade C). Should not be used for electrical applications, except for low voltage.

FBE (*Commercial Grade LE*). Made of fabric of same weight and thread count limits as FBI (grade L sheet). For electrical applications requiring greater toughness than PBG (grade XX). Better machining properties and finer appearance than FBG (grade CE), also available in thinner sizes. Exceptionally good in moisture resistance.

2–36. *Plastic Material, Laminated, Thermosetting, Electrical Insulating: Sheets, Type GMG*, MIL–P–15037, *Insulation Class B*

Laminated thermosetting sheets covered by this specification shall be of the following type:

Type GMG, glass cloth, melamine resin, general purpose.

The material is outstanding in thermal endurance and may be used in apparatus under severe temperature conditions for class B insulation. Furthermore, it has very low fire and toxicity hazards. It is selected for applications where it is desired to obtain good arc resistance and temperature stability with maximum fire resistance and minimum toxicity in case of fire.

2–37. *Plastic Material, Laminated, Thermosetting, Electrical Insulating: Sheets, Type GSG*, MIL–P–997, *Insulation Class H*

Laminated thermosetting sheets covered by this specification shall be of the following type:

Type GSG, glass cloth, silicone resin, general purpose.

This is a high-temperature insulating material having outstanding fire and arc resistance, highest thermal endurance, and very high insulation resistance with low dielectric loss characteristics.

2–38. *Insulation, Electrical, Mica Group M,* JAN–I–1139, *Insulation Class B*

These insulations are defined as group M. Group M is divided into three basic classes as:

Class NM, natural mica

Class PM, pasted mica*

Class RM, reinforced (mechanically) mica

Class PM is widely used as electrical insulation on machines. It is further subdivided into the following types:

Type PMR, pasted mica, rigid

Type PMM, pasted mica, moldable

Type PMF, pasted mica, flexible

Type PMH, pasted mica, heat resistant

Class RM is also widely used for electrical insulation and is subdivided into the following types:

Type RMC, reinforced mica, cloth

Type RMP, reinforced mica, paper

Type RMS, reinforced mica, synthetic

Type RMG, reinforced mica, glass fiber

2–39. *Insulation, Electrical, Coil and Slot, High-temperature,* 17–I–62, *Insulation Classes B and H*

High-temperature coil and slot electrical insulations are available in the following classes:

Class B, with organic varnish

Class H, with silicone varnish

High-temperature coil and slot electrical insulations are made in form S, sheet.

High-temperature coil and slot electrical insulation are of the following types:

Type Mg, pasted mica laminated with one layer of glass-fiber insulation.

Type Pmg, pasted mica laminated with one layer of paper insulation on one side and one layer of glass-fiber insulation on the other side. A high quality of electrical paper insulation is used.

*Now covered by HH–I–538.

Type Gmg, pasted mica sandwiched between single layers of glass-fiber insulation.

The foregoing class designations refer to the industry temperature standards, so that class B coil and slot insulation is suitable for operation at class B temperatures and likewise class H insulation is suitable for operation at class H temperatures.

2–40. CLOTH INSULATION

Cloth is an important form of insulation which has wide usage. Woven fabrics in cloth form are available both untreated and with various forms of varnish treatment. Insulating cloths are made with cotton, asbestos, glass, and a number of synthetic resin monofilament materials. Cloths have important advantages for electrical insulation both as physical binders and as dielectric barriers, but their application is limited by the shape of the parts to be insulated.

2–41. *Insulation, Electrical, Cotton Fiber, Untreated (CFU),* MIL–I–3042, *Insulation Class O*

Materials covered by this specification are furnished in but one type, namely, cotton fiber, untreated (CFU). They are made in six forms as follows: yarn, cord, tape, braid, sleeving, and cloth.

2–42. *Cambric, Insulating, Varnished,* 17C8, *Insulation Class A*

Varnished insulating cambric cloth covered by this specification is made in one type only—type A, cloth.

The varnished cambric insulating cloths are closely and uniformly woven cotton material free from defects. They are coated with multiple films of the highest grade of slow-drying baking varnishes.

2–43. *Insulation, Electrical, Asbestos Fiber, Untreated,* MIL–I–3053, *Insulation Class C*

Classes. Asbestos materials are furnished in the following classes with respect to total iron and magnetic iron content:

Class	Percent total iron (max.)	Percent magnetic iron (max.)
2	1.75	0.75
4	3.5	2.0
6	6.0	4.0

Types. Asbestos products are furnished in the following types with respect to class, condition as to treatment, and construction as to reinforcement:

Class	*Type*
2. Plain, untreated	2 PU
2. Reinforced, untreated	2 RU
4. Plain, untreated	4 PU
4. Reinforced, untreated	4 RU
6. Plain, untreated	6 PU
6. Reinforced, untreated	6 RU

Forms. Asbestos is furnished in the following forms:

1. Flock (milled or processed fiber).
2. Paper.
3. Rovings, yarns, cords, and fillers.
4. Tape.
5. Sleeving (tubular braids).
6. Cloth.

Grades. Asbestos is furnished in the following grades, as suitable for the intended application or as specified in the contract or order.

1. Arizona, grade 1, 2, 3, 4, or 5.
2. Rhodesian, grade 1, 2, 3, 4, or 5.
3. Russian, grade 1, 2, 3, 4, or 5.
4. Canadian, grade 1, 2, 3, 4, or 5.
5. Other.

Asbestos is most widely used in cloth for mechanical binding and physical support.

2–44. *Insulation, Electrical, Glass Fiber, Untreated,* MIL–I–1140A, *Insulation Class C*

Only one type of glass-fiber cloth is furnished as type GFU.

Glass-fiber fabrics are made from two classes of yarns:

Class CF, continuous filament
Class SF, staple fiber

2–45. *Insulation, Electrical, Glass Fiber, Varnished (Group GFV),* 17–I–45, *Insulation Classes B and H*

This treated fiber-glass material is made from type GFU (MIL–I–1140) and is available in two grades:

Grade O (class B) varnished with organic varnish, black and yellow.

Grade S (class H) varnished with silicone varnish, yellow.

Both are available in sheet form as form C, cloth.

2–46. *Insulation, Electrical, Synthetic Fiber, Untreated (SFU),* 17–I–34, *Insulation Class O*

This specification covers electrical insulation under the group symbol SFU. It covers several varieties of synthetic fiber cloth and tape. It is made in form C, cloth, and is available in two distinct types:

Type MMHR, medium mechanical heat resistant

Type HMHR, high mechanical heat resistant

The fabrics for these materials are formed from uniformly woven all-synthetic cloth with the warp and filling threads running at right angles. The material must not have a deleterious effect on copper, which might be caused by acidity with subsequent corrosion. The material must not be nutri-

ent to the growth of fungus. The materials must be suitable for impregnation with various grades of electrical insulating varnishes.

2–47. *Insulation, Electrical, Synthetic Fiber, Treated (SFT)*, 17–I–46, *Insulation Class A*

This specification covers fabrics woven of all synthetic filaments which are treated by impregnation with a suitable synthetic resin or varnish. These fabrics are described in Sec. 2–46. The finished product must have low water and moisture absorption, good corrosion resistance, and oil resistance. The insulation must not be a nutrient to mold and mildew. It is furnished in form C, cloth.

2–50. TAPE INSULATION

Tape is the most easily applied form of electrical insulation. It is used both for physical support and for dielectric barrier purposes. Most tapes are easily applied to odd shapes and are therefore extensively used. Tapes are made in both untreated and treated form from all the materials available in cloth form including cotton, asbestos, glass, and synthetic resin monofilaments. In addition tapes are made of rubber, synthetic films, and mica. There are other special adhesive tapes consisting of cotton or glass fabrics treated with one of several adhesive materials.

2–51. *Tape, Insulating (Electrical), Linen Finish, Plain*, JAN–T–638, *Insulation Class O*

Only one type of insulating tape (type I) is covered by this specification. The tape has a selvage edge, a smooth even finish which is commonly known as a "linen" finish. It is suitable in all respects for use in insulating electrical windings. The tape is unpressed and receives no chemical treatment whatever. It is so made that when finished it will have a reasonably smooth surface. This tape is primarily a separator until subsequent varnish treatment is applied.

2–52. *Cambric, Insulating, Varnished*, 17C8, *Insulation Class A*

Varnished insulating cambric tapes are designated as two types:

Type B, tape, bias cut

Type C, tape, straight cut

They are made from cloth described in Sec. 2–42 and have the same characteristics.

2–53. *Tape, Friction*, HH–T–101, *Insulation Class A*

Friction tape is made from cotton sheeting by thoroughly impregnating and heavily coating both sides with friction rubber compound. The rubber compound exists in an unvulcanized state and has good adherence to adjacent turns of itself. The material is used for sealing outer layers of insulation that is applied to cable joints and junctures in wiring around frames. Although it has relatively good insulating properties, it is not used as the major insulation, but only as the finishing tape over rubber tape, varnished cambric tape, or mica tape.

2–54. *Insulation, Electrical, Asbestos Fiber, Treated*, MIL–I–3053, *Insulation Class B*

Treated asbestos cloth is made by applying varnish treatment to the untreated cloths described in Sec. 2–43. It is available in the following types with respect to class and reinforcement construction:

Class	*Type*
2. Plain, treated	2 PT
2. Reinforced, treated	2 RT
4. Plain, treated	4 PT
4. Reinforced, treated	4 RT
6. Plain, treated	6 PT
6. Reinforced, treated	6 RT

2–55. *Insulation, Electrical, Glass Fiber, Untreated,* MIL–I–1140A, *Insulation Class C*

Tape form is similar in physical characteristics to cloth form described in Sec. 2–44.

2–56. *Insulation, Electrical, Glass Fiber, Varnished (Group GFV),* 17–I–45, *Insulation Classes B and H*

This general group of material (GFV) is available in tape identified as form T in both grade O with organic varnish and grade S with silicone varnish. Otherwise similar to cloth described in Sec. 2–45.

2–57. *Insulation, Electrical, Coil and Slot, High Temperature,* 17–I–62, *Insulation Classes B and H*

Form T, tape

Glass-mica tape is similar in general construction to slot insulation described in Sec. 2–39.

2–58. *Tape, Rubber (Natural and Synthetic), Insulating,* HH–T–111, *Insulation Class A*

This specification covers unvulcanized or partially vulcanized compounds of natural rubber and synthetic rubbers and mixtures. The material is made in tape form for application as insulation, having good dielectric strength. When pressed together the tape will fuse into a solid mass which will exclude moisture. It is used particularly for taping joints in cables and in wiring around frames in electrical machinery.

2–59. *Insulation, Electrical, Synthetic Fiber, Untreated (SFU),* 17–I–34, *Insulation Class O*

Form T, tape

This covers the same materials described in Sec. 2–46 except in tape form.

2–61. *Insulation, Electrical, Synthetic Fiber, Treated (SFT),* 17–I–46, *Insulation Class A*

Form T, tape

Treated synthetic fiber tape SFT is otherwise similar to form C, cloth, described in Sec. 2–47.

2–62. *Insulation, Electrical, Synthetic Resin Composition, Nonrigid,* JAN–I–631, *Insulation Class A*

This specification covers synthetic resin insulation in a variety of types and forms as follows:

Type A, polyethylene
Type B, cellulose acetate butyrate
Type C, cellulose acetate
Type D, ethyl cellulose
Type E, vinylidene chloride
Type F, polyvinyl chloride and copolymers of vinyl chloride and vinyl acetate
 Grade (*a*), general purpose
 Grade (*b*), low temperature

As a sheet and tape material it is made in these forms:

Form F, film, in rolls
Form S, sheet, flat or in rolls
Form T, tape

All these materials are made of suitable synthetic resin compositions formulated with plasticizers, pigments, fillers, or other ingredients necessary to provide flame resistance and physical properties as well as suitable electrical properties.

2–63. *Tape, Insulating, Electrical, Pressure-sensitive, Adhesive,* 17–T–28, *Insulation Class A*

This specification covers pressure-sensitive adhesive electrical insulating tape of the following types:

Type AF, acetate film backing (yellow)
Type AC, acetate cloth backing (white)
Type CF, cotton fabric backing (white)

Type GF, glass fabric backing (white)
Type PC, paper backing, crepe (yellow)
Type PF, paper backing, flat (yellow)
Type VF, vinyl chloride, acetate backing (black)
Type EF–9, Polyethylene backing (yellow)
9 mils nominal thickness of tape
Type EF–20, polyethylene backing (yellow)
20 mils nominal thickness of tape

The material has good electrical properties, but is primarily used for sealing.

2–70. ROD INSULATION

Insulation in rod form is primarily used for mechanical support where some insulating characteristics are required. It has limited application in rotating electrical machinery and is more widely used in control, switch gear, and transformers.

2–71. *Fibre*, *Insulation* JAN–F–1148, *Insulation Class O*

Form R, rods

Fibre rods are made from the same materials referred to in Sec. 2–33.

2–72. *Plastic Materials*, *Laminated*, *Thermosetting: Rods*, MIL–P–79, *Insulation Class A*

Paper-base laminates, form R
See Sec. 2–103 for comparable tubing.

2–73. *Plastic Materials*, *Laminated*, *Thermosetting: Rods*, MIL–P–79, *Insulation Class A*

Organic fabric-base laminates, form R
See Sec. 2–104 for comparable tubing.

2–74. *Plastic Materials*, *Laminated*, *Thermosetting: Rods*, MIL–P–79, *Insulation Class B*

Glass fabric-base laminates, form R
See Sec. 2–105 for comparable tubing.

2–80. CORDAGE INSULATION

Tying cords are an important form of electrical insulation. They perform important mechanical functions in tying and lashing coils to each other and to support members as well as in binding other insulating parts and creepage surfaces.

2–81. *Insulation*, *Electrical*, *Glass Fiber*, *Untreated*, MIL–I–1140A, *Insulation Class C*

For general properties and classes of this insulation refer to Secs. 2–22 and 2–44. It is used in the form:

Cordage, twisted and braided

2–90. VARNISHED TUBING AND SATURATED SLEEVING INSULATION

The term "varnished tubing" refers to braided cotton, rayon, nylon, or fiber-glass sleeving coated or impregnated and coated with varnish, lacquer, or a combination of lacquer and varnish or similar coatings. The term "saturated sleeving" refers to braided cotton, rayon, nylon, or fiber-glass sleeving impregnated with varnish, but the coating need not be continuous as it must for varnished tubing. The first letter of the class designation refers to the industry standard temperature classes A, B, and H. The subsequent letters and numerals denote processing technique and treating materials as required in Specification MIL–I–3190 and shown in detail on page 61.

2–91. *Sleeving*, *Insulating*, *Cotton*, MIL–I–3042, *Insulation Class O*

The materials covered by this specification are of only one type or form. This covers cotton insulating sleeving for general insulation purposes, and the material is untreated in the form supplied by manufacturers. It is suitable for treatment with various electrical insulating varnishes.

Class	Impregnate only	Coating continuous film	Impregnate and continuous film	Varnish
A-A-1			X	Oleoresinous
A-A-2		X		Lacquer or spirit
A-B-1		X		Oleoresinous
A-B-2			X	Lacquer or spirit
A-C-1	X*			Oleoresinous
B-A-1			X	Oleoresinous
B-A-2			X	Lacquer or spirit
B-B-1		X		Oleoresinous
B-B-2			X	Lacquer or spirit
B-C-1	X*			Oleoresinous
H-A-1			X	Silicone
H-B-1			X	Silicone
H-C-1	X*			Silicone

* Coating need not be continuous.

2-92. *Insulation, Electrical, Sleeving Flexible, Treated,* MIL-I-3190, *Insulation Class A*

Organic fabric sleevings described in Sec. 2-91 are treated with various varnishes by several methods reviewed in Sec. 2-90 to produce the following classes described in Sec. 2-90:

A-A-1
A-A-2
A-B-1
A-B-2
A-C-1

2-93. *Insulation, Electrical, Asbestos Fiber, Untreated,* MIL-I-3053, *Insulation Class C*

Untreated asbestos sleeving is similar to untreated asbestos cloth described in Sec. 2-43 except as to form.

2-94. *Insulation, Electrical, Glass Fiber, Untreated,* MIL-I-1140A, *Insulation Class C*

Untreated fiber-glass sleeving is similar to untreated fiber-glass cloth described in Sec. 2-44 except as to form.

2-95. *Insulation, Electrical, Sleeving Flexible, Treated,* MIL-I-3190, *Insulation Classes B and H*

Fiber-glass fabric sleeving described in Sec. 2-94 is treated with various varnishes by several methods reviewed in Sec. 2-90 to produce the following classes:

B-A-1
B-A-2
B-B-1
B-B-2
B-C-1
H-A-1
H-B-1
H-C-1

2-96. *Insulation, Electrical, Synthetic Resin Composition, Nonrigid,* JAN-I-631, *Insulation Class A*

Synthetic sleeving under this specification is made of the synthetic resin film material described in Sec. 2-62. It is identified as form U, tubing.

2-100. TUBING INSULATION

Insulation in rigid tubular form is useful for many specific applications both as

physical support and for dielectric purposes.

2–101. *Fibre, Insulating,* JAN–F–1148, *Insulation Class O*

Form T

Fibre tubes are made from the same materials described in Sec. 2–33.

2–102. *Insulation, Electrical, Pasted Mica,* HH–I–538, *Insulation Class B*

Form T

Tubes of fabricated resin-bonded mica products are similar in composition and properties to other forms of the same type referred to in Sec. 2–38.

2–103. *Plastic Materials, Laminated, Thermosetting: Tubes,* MIL–P–79, *Insulation Class A*

Tubes are available in two forms:

Form T_r, tubing, rolled

Form T_m, tubing, molded

See Sec. 2–34 for basic characteristics of materials of corresponding classes.

PBM (*Commercial Grade X*). T_r, good punching and fair machining qualities. Low power factor and high dielectric strength under dry conditions.

T_m, better in moisture resistance and machining qualities than rolled. Strongest paper base except in thin walls. Dielectric strength may be low at molded seams.

PBG (*Commercial Grade XX*). T_r, good machining, punching, and threading qualities. Not so strong mechanically as PBM rolled, but better moisture resistance. Better grade for low dielectric losses, particularly on exposure to high humidity.

T_m, better in moisture resistance than PBG rolled or than PBM. Good machining and good electrical properties, except in very thin walls where the dielectric strength may be low at the molded seams.

PBE (*Commercial Grade XXX*). T_m, similar characteristics to corresponding sheet except as limited by the inherent differences in construction and shape.

2–104. *Plastic Materials, Laminated, Thermosetting: Tubes,* MIL–P–79, *Insulation Class A*

FBM (*Commercial Grade C*). T_r, made from a cotton fabric with the same weight and thread-count limits as for sheets of this grade.

FBG (*Commercial Grade CE*). T_m, for use where a tough, dense, fabric-base material is required, having fair electrical properties along with excellent mechanical properties and good resistance to moisture. Dielectric strength may be low at molded seams, especially in thin walls.

FBI (*Commercial Grade L*). T_m, made from fine-weave cotton fabric. Has high density and good moisture resistance. For mechanical applications primarily where finer machined appearance than FBG molded is desired or where tougher material than FBE molded is required. Should not be used for electrical applications except for low voltage.

FBE (*Commercial Grade LE*). T_r, best concentricity and dielectric strength of any fabric-base grade. For use where the seams from a molded tube may be objectionable and where the application requires good machining qualities, together with good electrical and mechanical properties.

T_m, has excellent machining and moisture-resisting characteristics. For use in electrical applications even under humid conditions where a tougher material than PBG tubing is required at some sacrifice of electrical properties. Dielectric strength may be low at molded seams, especially in thin walls. Better electrically than FBG molded, but not quite so tough.

2–105. *Plastic Materials, Laminated, Thermosetting: Tubes*, MIL–P–79, *Insulation Class B*

Glass fabric base:

Types GBH and GBM, mechanical properties predominate

Type GMG, general use. Properties still under investigation

Type GBE, outstanding electrical properties

2–110. MICA

Natural mica is the outstanding electrical insulating material, as it possesses important properties in three fields, namely, electrical, physical, and chemical. Refer to Secs. 2–10 and 2–23 for a more comprehensive discussion of the properties of mica.

2–111. *Insulation, Electrical, Mica (Group M)*, JAN–I–1139, *Insulation Class C*

Natural mica is available under this specification in class NM and the following types:

- Muscovite
  - Type NMH, heavily stained
  - Type NMS, stained
  - Type NMG, good stained
  - Type NMF, fair stained
  - Type NMS, slightly stained
- Phlogopite
  - May be of amber or silver color

Natural mica consists entirely of selected fragments of naturally occurring minerals without bond or organic supporting members. It is obtainable in form S, sheets, trimmed (uncut) or dimensioned (cut), and form W, washers.

Grading of NM mica and mica splittings under JAN–I–1139 conforms to the commercial grading numbered system as outlined in Fig. 2–1.

2–120. THIN FIBRE INSULATION

Organic resins in thin sheets or films have many uses in the manufacture of composite electrical insulations. They are also used separately for various insulating purposes. Their most common use is as strong, tough, thin structural members to support other insulations which are not so resistant to mechanical damage.

2–121. *Insulation, Electrical, Synthetic Resin Composition, Nonrigid*, JAN–I–631, *Insulation Class O or A*

Refer to Sec. 2–62 for general review of types of materials under this specification. It is available as:

Form F, film in rolls

Form S, sheet, flat or in rolls

2–130. VARNISHES AND LIQUID INSULATION

Varnishes, enamels, and liquid insulations comprise an important group of insulating materials. They supplement and protect all other types of insulation against moisture, chemical contaminants, and aging. The basic constituents of varnishes are discussed in detail in Sec. 2–11 and the methods of application are described in Chap. 5. The following sections describe the available materials for use on Navy apparatus.

2–131. *Varnish, Insulating (Electrical)*, JAN–V–1137, *Insulation Class A or B*

There are five grades of organic electrical insulating varnishes described as follows:

Grade BA, black, air-drying, insulating

Grade BB, black, baking, insulating

Grade CA, clear, air-drying, insulating

Grade CB, clear, baking, insulating

Grade CF, clear, finishing

Varnishes are further segregated as type M varnishes and type N varnishes. The

type M varnishes are those which are approved for application by manufacturers in their factories or repair shops. This approval is entirely on the basis of performance characteristics of the finished varnish films. Type N varnishes include all the performance requirements for type M varnishes of the corresponding grades. In addition the type N varnishes must contain only certain solvents and thinners which are acceptable for use on shipboard. Solvents and thinners for type N varnishes are carefully restricted as to flash point, solvency power, and distillation range as well as the type of compound permitted by health considerations. For example, type N varnishes may not contain more than 1 percent benzene; methanol and ethanol may not be present.

The general requirements for these varnishes include the following performance characteristics:

1. The insulating varnish shall be suitable for application and use on electrical windings and other parts of electrical apparatus. It must preserve the initial dielectric strength of the insulation to which it is applied by the exclusion of moisture, oil and grease, acids, sea water, or other deleterious substances to which electrical apparatus may be subjected in Naval service.

2. The varnish shall be chemically stable under conditions of heat and moisture met in Naval service.

3. The varnish must pass a fresh-water immersion test wherein the insulation resistance of a cured film shall, after 240 hours' immersion, be not less than 1 megohm for a specific area of test specimen.

4. The hardness of the cured film shall be within the limits prescribed in the specification.

5. The insulation resistance of a varnish film of a certain area shall not be less than 1 megohm after being subjected to an acidproofness test and a sea-waterproofness test similar to the fresh-water immersion.

6. The varnish must not show pimpling or lifting of the film or be soluble in or affected by transformer oil.

7. The varnish must not corrode copper, brass, or steel.

8. The varnish must be capable of being applied in continuous films so that the dried varnish film does not show imperfections such as streaking, silking, striation, cissing, or other abnormal conditions.

9. The hiding power of black grades of varnish must be such that plate-glass panels prepared in a certain manner give a light transmission of not more than 0.5 percent. No limitations are established for the color of clear-grade insulating varnishes, and color standards are used solely for identification purposes.

Property	Grade				
	BA	BB	CA	CB	CF
Drying time, hours (max.)	8	10	8	10	8
Dielectric strength, wet, volts per mil (min.)	300	450	325	550	350
Dielectric strength, dry volts per mil (min.)	600	1,067	667	1,067	667
Acidproofness, hours (min.)	200	240	200	240	300
Sea-waterproofness, hours (min.)	200	240	200	240	300
Flexibility, heat endurance, hours (min.)	300	500	200	500	100

10. Varnish films shall have a certain minimum flexibility or heat endurance as specified.

11. The varnish film prepared on a copper panel shall have a specific minimum dielectric strength when tested dry and after immersion in fresh water for 24 hours.

The curve of Fig. 5–6 shows the thermal endurance of a number of varnishes at several temperatures.

The table on page 64 lists these performance requirements for both type M and type N varnishes for JAN–V–1137.

There are numerous other requirements for varnishes many of which are identity tests and do not relate to the specific performance characteristics of the materials. Grade CB (clear baking) type varnishes should be used in preference to all other grades for maximum performance.

2–132. *Insulation, Electrical, Liquid, Impregnating, High-temperature, Insulation Class H*

This covers two classes of high-temperature silicone insulating varnish which are applicable by baking only. The two grades of silicone varnishes are:

Grade HTB, high-temperature baking for processing at temperatures in the range of 225 to 235 C.

Grade LTB, low-temperature baking for processing at temperatures in the range of 135 to 150 C.

These high-temperature silicone-resin varnishes are suitable for coil impregnation and varnish treatment of class H coils and apparatus. Except for the thermal endurance of the baked film, the performance characteristics are quite similar to those for conventional organic varnishes in specification JAN–V–1137 as reviewed in Sec. 2–131. The significant performance characteristics are shown in the table below.

2–133. *Insulating Material, Electrical, Liquid, Quick-drying*, 17–I–16, *Insulation Class A or B*

The liquid insulation covered by this specification is a quick-drying lacquer for application by brushing, dipping, or spraying. It hardens and forms an insulating film on the surface to which it is applied. It is available in clear, dull black, red, and clear gloss. This liquid dries in 1 hour at room temperature. It possesses good resistance to weak acids, high resistance to water, and good heat endurance. It is relatively oilproof and has good hiding power. It is primarily used as a surface

Property	Grade	
	HTB	LTB
Weight loss, percent (max.)	12 (at 250 C)	8 (at 150 C)
Dielectric strength, dry, volts per mil (min.)	800	800
Dielectric strength, wet, volts per mil (min.)	300	300
Crazing resistance after aging at 250 C (482 F), hours (min.)	200	200
Cold-checking temperature:		
Deg C	−55	−55
Deg F	−67	−67

treatment on electrical insulation to improve the appearance.

2–134. *Insulation, Electrical, Plastic Sealer,* MIL–I–3064, *Insulation Class A or B*

Plastic sealer compound is for use in sealing openings and filling voids in electrical insulation. It has a consistency that can be readily worked with the fingers or a knife and is capable of being drawn or kneaded into long, thin rods. It is suitable for application at room temperature, 30 C or less. The material is oilproof, has good water resistance, and is relatively noninflammable. The material has high insulation resistance and must not break down on application of a 1,500-volt a-c test for 1 minute in ½ inch thickness.

2–140. MAGNET WIRE AND INSULATION

The purpose of this manual is to cover insulation and windings, but copper is almost inseparable, as the major objective of insulation is to confine the electric current to copper conductors. A brief summary of copper characteristics and wire standards is therefore in order.

There are many wire gauges, but the American Wire Gauge (AWG) is now the American standard. This was devised by J. R. Brown in 1857 and is also called the Brown & Sharpe (B & S) gauge. This gauge system is based on a constant ratio of areas between consecutive wire sizes. The ratio between the diameter of any size wire and the next smaller size is 1.122932. The ratio of areas of the consecutive wire sizes is approximately 1.26. Therefore, the resistance per unit length of successive wire sizes is the inverse ratio of the area (1/1.26, or 0.794) for the resistivity of the next larger size. The AWG system is based on the diameter of No. 0000 wire being 0.4600 inch and the diameter of No. 36 wire being 0.005 inch. Hence there are 38 sizes between the two and 39 steps from No. 0000 to No. 36.

Standard wire sizes always refer to copper sizes. The insulated size of the wire depends upon the type of insulation used. As some insulations are much thicker than others, there is a wide variation in the space occupied by copper when different types of wire covering are used. The percentage of the total winding space occupied by copper is called the "space factor."

A wide variety of magnet-wire coverings is available commercially, and all have some desirable characteristics to recommend them. The various standard materials and the ASA designations are listed in Fig. 2–5. The most important consideration in the selection of magnet-wire insulation is to recognize the dielectric strength limitations of all magnet-wire coverings. *The insulation dielectric of magnet-wire coverings should be considered to be that of the equivalent spacing.* Dielectric tests on wire samples should be recognized as comparative only. Magnet-

PROPERTIES OF ANNEALED COPPER

Specific gravity	8.89
Weight	0.321 lb per cu in.
Resistivity (25 C = 77 F)	10.5 ohms per circular mil foot
Coefficient of resistivity (25 C = 77 F)	0.00386 per deg C 0.00214 per deg F
Specific heat	3.25 watt-min per lb per deg C 1.8 watt-min per lb per deg F
Thermal conductivity (100 C = 212 F)	9.7 watts per sq in. per deg C per in. thickness 5.4 watts per sq in. per deg F per in. thickness
Tensile strength	30,000 lb per sq in.
Coefficient of expansion	0.000017 per deg C 0.0000094 per deg F

Fig. 2-4. Industry Standard Abbreviations—Magnet-wire Symbols

(Army-Navy nomenclature differs in some respects. See Sec. 2-141)

Basic Magnet-wire Letter Symbols

Asbestos	A
Bonded	B
Cotton	C
Double	D
Enamel	E
Glass	G
Heavy	H
Cellophane	K
Cellulose acetate	L
Paper	P
Silk	S
Thermoplastic (synthetic)	T
Varnish-treated (including silicone)	V

Combination insulations are specified by using the approved letter symbols in the order of application to the conductor. A list of popular combinations of the above and their proper symbol indications follows:

Asbestos Covered

Single asbestos	A
Single asbestos varnish	AV

Enameled

Enamel	E
Heavy enamel	HE

Cotton Covered

Single cotton	C
Bonded single cotton	BC
Single cotton varnish	CV
Double cotton	DC
Bonded double cotton	BDC
Double cotton varnish	DCV
Heavy double cotton	HDC

Paper and Cotton Covered

Single paper single cotton	PC
Single paper double cotton	PDC
Double paper single cotton	DPC
Double paper double cotton	DPDC

Silk and Cotton Covered

Single cotton single silk	CS
Single cotton double silk	CDS
Double cotton single silk	DCS
Double cotton double silk	DCDS

Thermoplastic Insulated

Single	T
Heavy	HT
Triple	TT
Quadruple	QT

Glass Insulated

Single glass	G
Double glass	DG
Single enamel single glass	EG
Heavy enamel single glass	HEG

Cellulose Acetate Covered

Single acetate	L
Single enamel single acetate	EL
Single acetate single cotton	LC
Double acetate	DL

Cellophane Covered

Single cellophane	K
Single enamel single cellophane	EK
Heavy enamel single cellophane	HEK

Enamel and Cotton Covered

Enamel single cotton	EC
Enamel bonded single cotton	EBC
Enamel single cotton varnish	ECV
Enamel double cotton	EDC
Enamel bonded double cotton	EBDC
Enamel double cotton varnish	EDCV
Heavy enamel single cotton	HEC
Heavy enamel bonded single cotton	HEBC
Heavy enamel single cotton varnish	HECV
Heavy enamel double cotton	HEDC
Heavy enamel bonded double cotton	HEBDC
Heavy enamel double cotton varnish	HEDCV

Silk Covered

Single silk	S
Bonded single silk	BS
Single silk varnish	SV
Double silk	DS
Bonded double silk	BDS
Double silk varnish	DSV
Enamel single silk	ES
Enamel bonded single silk	EBS
Enamel single silk varnish	ESV
Enamel double silk	EDS
Enamel bonded double silk	EBDS
Enamel double silk varnish	EDSV
Heavy enamel single silk	HES
Heavy enamel bonded single silk	HEBS
Heavy enamel single silk varnish	HESV
Heavy enamel double silk	HEDS
Heavy enamel bonded double silk	HEBDS
Heavy enamel double silk varnish	HEDSV

Paper Covered

Single paper	P
Single paper bonded	BP
Double paper	DP
Double paper bonded	DPB

Enamel and Paper Covered

Enamel single paper bonded	EBP
Enamel double paper bonded	EBDP
Heavy enamel single paper bonded	HEBP
Heavy enamel double paper bonded	HEBDP

wire covering should be selected on the basis of physical strength, temperature classification, space factor, and ability to withstand winding abuse rather than dielectric strength as evaluated by laboratory tests.

The recognized basic wire coverings are summarized in the following, which comments briefly concerning the characteristics of each and the temperature classification:

Asbestos (*A*). Covering may be "felted on" or applied as a tape. It partakes of the characteristics of the basic asbestos and varnish (when treated). This wire may be either class B or class H insulation depending upon the type of varnish treatment.

Cotton (*C*). Insulation is always applied as a yarn in one or more thicknesses. It is seldom if ever varnish-treated and is class O or class A insulation depending upon varnish treatment employed on the finished coil.

Enamel (*E*). This is the thinnest type of insulation which has the best space factor. It is a class A insulation.

Glass (*G*). Glass is applied in the same manner as cotton and is nearly always varnish-treated. It is either class B or class H depending upon the type of varnish used.

Cellophane (*K*). This is a specialized class A wire covering.

Cellulose Acetate (*L*). This is another special form of class A wire covering.

Paper (*P*). Paper covering is widely employed both alone and in combination with enamel. It is a class O or class A insulation depending upon whether or not varnish treatment is employed.

Silk (*S*). Silk is the thinnest variety of fiber wire covering. It is class O or class A depending upon whether varnish-treated.

Thermoplastic (*Synthetic*) (*T*). This is a special form of enamel and includes those varieties commonly termed Formex or Formvar. It is class A insulation.

2–141. *Wire, Magnet*, JAN–W–583

Insulated magnet wire is available for all temperature classes of insulation. This specification covers a variety of types as tabulated below. Where no numeral is included in the type designation, single covering is indicated. The inclusion of numerals 2 or 4 designates double or quadruple covering. The nomenclature follows general industry practices as shown in Fig. 2–4 with several important changes.

The copper conductors under this specification are solid individual wires, either round or rectangular in shape.

Complex combinations of these basic types of wire covering are also made for special applications. These are described at length in JAN–W–583.

Type designation	Insulation class	Insulation
C	O or A	Cotton
E	A	Enamel
F	O and A	Fiber, synthetic
R	A	Resin
P	O or A	Paper
A	B	Asbestos, impregnated with a moisture-resisting compound
AV	B	Asbestos, impregnated with varnish
GV	B	Glass yarn, impregnated with varnish or other insulation having adequate moisture-resisting properties
GH	H	Glass yarn, impregnated with a high-temperature silicone varnish

3. Selection of Insulating Materials and Construction of Coils, Commutators, Slip Rings, and Brush Holders

The primary function of electrical insulation on coils is to guide the current through useful channels without leakage into undesired paths. Insulation on coils must possess many important electrical properties such as great dielectric strength, high electrical resistivity, low dielectric loss, and resistance to moisture absorption. These primary properties will determine the electrical effectiveness of the insulation, but the physical properties are at least as important as the electrical ones. Insulation must be capable of withstanding severe mechanical abuse during the manufacturing operations as well as reasonable physical stress during its operating life. Properties such as tensile strength, compressive strength, resistance to abrasion, flexural strength, tear strength, and bond strength plus ability to withstand bending without loss of electrical properties are all of importance. The chemical properties of insulating materials are also of equal importance. Insulations must be resistant to oils and common solvents and must not be damaged seriously by weak acids and alkalies. Low inflammability is desirable especially for shipboard applications. It is also desirable that materials be resistant to ozone degradation when exposed to corona. **Thermal stability is probably the most important chemical property, as the thermal aging of insulation is known to be one of the most significant properties in determining the life of a winding.** Coils of machines are supported on insulation, and often the individual conductors are completely surrounded by insulation. Since the heat generated within the winding must

be dissipated through the insulation, the thermal conductivity of the material is important.

3-1. SELECTING INSULATING MATERIALS

The selection of the best insulating material for a specific application usually involves a compromise, as no single material will have all the desired properties at the highest possible level. The following step-by-step procedure is suggested in attacking the problem of material selection:

1. Review the requirements of the application carefully, and consider the conditions under which the apparatus operates. Decide whether the mechanical, electrical, chemical, or thermal aging properties are predominant in the selection of materials.
2. Review the general description of the types of materials, and select a material with suitable general properties in line with the primary requirements for the application.
3. Examine tables listing the properties of materials, and select several possible materials which might be considered. Compare the normal values for the materials as listed in the table for this property. Consider whether or not fabrication will reduce the level of the desired property. Materials should not be selected on the basis of what is best in material characteristics or most expensive but should be selected on the basis of what will meet the requirements adequately and economically for the service conditions.
4. Estimate the working dielectric stress on the insulating material during operation and during testing to determine whether a suitable factor of safety exists. **Usually the materials should have an intrinsic strength at least double the level of the final overpotential test to be applied to the finished coil.**

3-2. TYPES OF WINDINGS

The two main types of windings for motors employ (1) random-wound coils and (2) form-wound coils. Generators are usually larger machines and therefore ordinarily employ form-wound coils only. Random windings are used in so-called "partially closed slot" motors, which include nearly all fractional horsepower motors (both a-c and d-c) and many of the smaller integral horsepower induction motors. Form-wound coils are used in "open-slot" motors and generators. The size, voltage rating, efficiency, power factor, and cost of the machine determine the choice of winding type.

Random winding, as the name indicates, refers to a winding process whereby the wire is wound directly into the core slots. The wires lie in whatever position they happen to be laid down. On this type of winding enameled wire with class A insulation details is used quite generally. Other forms of wire insulation are sometimes used with class B or class H insulations. The wire is inserted directly by hand or machine into the slots. Frequently the wire is wound into coils on a shuttle before it is placed in the slots. The slots are protected by "slot-armor" or "slot-cell" insulation made up of a combination of one of a wide variety of insulations. It is important that this armor protect the windings both electrically and mechanically. During the winding operation the turns must be protected from the sharp edges of the punchings. As an insulation, the slot armor or cell must have a high dielectric strength and good moisture resistance. After the requisite number of turns have been in-

serted in the slots and the projecting loops shaped down, a "slot stick" or "wedge" is slid in over the windings, closing each slot. Figure 3–1 lists the more common varieties of insulations for random-wound d-c armatures, and Fig. 3–2 shows corresponding insulating materials used in random-wound a-c stators. Both charts list insulating materials according to the standard temperature classifications.

FIG. 3–1. GENERAL APPLICATION OF INSULATION TO D–C MOTOR ARMATURES WITH RANDOM WINDINGS

Insulation application	Insulation class		
	A	B	H
Turn and strand insulation (on conductors)	Enamel covering Paper covering Cotton covering	Asbestos covering Glass covering	Asbestos covering* Fiber-glass covering*
Ground insulation (slot cell or armor)	Fish paper Fish paper and varnished cloth Fish paper and mica	Fish paper and mica Fiber-glass cloth and mica Molded mica	Fiber-glass cloth and mica* Molded mica*
Lead and connection insulation	Synthetic resin tubing Varnished cotton tubing	Varnished asbestos tubing Varnished fiber-glass tubing	Varnished asbestos tubing* Varnished fiber-glass tubing*
Binder insulation (tape on diamonds)	Cotton tape Synthetic-fiber cloth tape	Asbestos tape Fiber-glass tape	Asbestos tape Fiber-glass tape
Slot sticks or wedges	Wood Fibre Paper or cotton laminate	Phenolic laminates Melamine laminates (usually with asbestos or fiber-glass cloth)	Asbestos-silicone laminate Fiber-glass–silicone laminate
Band insulation	Varnished cotton cloth Varnished synthetic-resin cloth Fish paper	Fish paper and mica Flexible mica Varnished asbestos Varnished glass	Fiber glass and mica* Flexible mica* Varnished asbestos cloth* Varnished fiber glass

* Treated or bonded with silicone resin only.

Conventional wedge materials are no longer permissible on electric machinery for Navy service. Flat slot wedges for all class A and B insulated motors should be glass-melamine laminated. Formed slot wedges made of fibre are acceptable on class A insulated motors.

For class B motor insulation any organic paper (for structural support of mica or mica-glass ground or end insulation) must be of minimum thickness, preferably not over 0.003 inch.

FIG. 3–2. GENERAL APPLICATION OF INSULATION TO A–C INDUCTION MOTOR STATORS WITH RANDOM WINDINGS

Insulation application	Insulation class A	Insulation class B	Insulation class H
Turn and strand insulation (on conductors)	Enamel covering Paper covering Cotton covering	Asbestos covering Glass covering	Asbestos covering* Fiber-glass covering*
Ground insulation (slot cell or armor)	Fish paper Fish paper and varnished cloth Fish paper and mica	Fish paper and mica Fiber-glass cloth and mica Molded mica	Fiber-glass cloth and mica* Molded mica*
Phase insulation (between phase groups on coil diamonds)	Fish paper Varnished cotton cloth Varnished synthetic-resin cloth Fish paper and treated cloth	Fish paper and mica Flexible mica Fiber glass and mica	Fiber glass and mica* Flexible mica*
Lead and connection insulation	Synthetic resin tubing Varnished cotton tubing Varnished cotton tape Cotton tape	Varnished asbestos tubing Varnished fiber-glass tubing	Varnished asbestos tubing* Varnished fiber-glass tubing*
Binder insulation	Cotton tape Synthetic-fiber cloth tape	Asbestos tape Fiber-glass tape	Asbestos tape Fiber-glass tape
Slot sticks or wedges	Wood Fibre Paper or cotton laminate	Phenolic laminates Melamine laminates (usually with asbestos or fiber-glass cloth)	Asbestos-silicone laminate Fiber-glass–silicone laminate
Lacing and tying cord (end-winding support)	Cotton twine Flax twine	Asbestos twine or sleeving Fiber-glass twine or sleeving	Asbestos twine or sleeving* Fiber-glass twine or sleeving*

* Treated or bonded with silicone resin only.

Conventional wedge materials are no longer permissible on electric machinery for Navy service. Flat slot wedges for all class A and B insulated motors should be glass-melamine laminated. Formed slot wedges made of fibre are acceptable on class A insulated motors.

For class B motor insulation any organic paper (for structural support of mica or mica-glass ground or end insulation) must be of minimum thickness, preferably not over 0.003 inch.

FIG. 3-3. GENERAL APPLICATION OF INSULATION TO D-C MOTOR AND GENERATOR ARMATURES WITH FORMED PREINSULATED COILS

Insulation application	Insulation class		
	A	B	H
Turn and strand insulation (on conductors or applied after coils are formed)	Cotton-covered wire Paper-covered wire Enameled strap Cotton-taped strap	Asbestos-covered wire and strap Fiber-glass-covered wire and strap Fiber-glass-taped strap Mica-taped strap	Fiber-glass-covered wire and strap* Fiber-glass-taped strap* Mica-taped strap*
Ground insulation (wrappers or layers of tape)	Fish paper Fish paper and treated cloth Varnished cotton cloth (wrapper or tape) Varnished synthetic resin Cloth (wrapper or tape) Fish paper and mica	Fish paper and mica Pasted mica Fiber glass and mica Mica tapes	Fiber glass and mica* Pasted mica* Mica tapes*
Lead insulation†	Cotton tape Varnished cotton tape	Mica tape Fiber-glass tape Varnished fiber-glass tape	Mica tape* Fiber-glass tape*
Binder insulation (finishing tape all over coil surface)	Cotton tape Synthetic-fiber cloth tape	Asbestos tape Fiber-glass tape	Asbestos tape Fiber-glass tape
Slot sticks or wedges	Wood Fibre Paper or cotton laminate	Phenolic laminates Melamine laminates (usually with asbestos or fiber-glass cloth)	Asbestos-silicone laminate Fiber-glass–silicone laminate
Band insulation	Varnished cotton cloth Varnished synthetic-resin cloth Fish paper	Fish paper and mica Flexible mica Varnished asbestos Varnished glass	Fiber glass and mica* Flexible mica* Varnished asbestos cloth* Varnished fiber-glass cloth*

* Treated or bonded with silicone resin only.

† Frequently coil-turn insulation suffices.

Conventional wedge materials are no longer permissible on electric machinery for Navy service. Flat slot wedges for all class A and B insulated motors should be glass-melamine laminated. Formed slot wedges made of fibre are acceptable on class A insulated motors.

For class B motor insulation any organic paper (for structural support of mica or mica-glass ground or end insulation) must be of minimum thickness, preferably not over 0.003 inch.

FIG. 3-4. GENERAL APPLICATION OF INSULATION TO A-C MOTOR AND GENERATOR ARMATURES WITH FORMED PREINSULATED COILS

Insulation application	Insulation class		
	A	B	H
Turn and strand insulation	Cotton-covered wire Paper-covered wire Enameled strap Cotton-taped strap	Asbestos-covered wire and strap Fiber-glass-covered wire and strap Fiber-glass-taped strap Mica-taped strap	Fiber-glass-covered wire and strap* Fiber-glass-taped strap* Mica-taped strap*
Ground insulation (wrapper or layers of tape)	Fish paper Fish paper and treated cloth Varnished cotton cloth (wrapper or tape) Varnished synthetic-resin cloth (wrapper or tape) Fish paper and mica	Fish paper and mica Pasted mica Fiber glass and mica Mica tapes	Fiber glass and mica* Pasted mica* Mica tapes*
Lead insulation†	Cotton tape Varnished cotton tape	Mica tape Fiber-glass tape Varnished fiber-glass tape	Mica tape* Fiber-glass tape*
Phase insulation (extra tape on diamonds of phase coils)	Varnished cotton cloth tape Varnished synthetic-resin cloth tape	Mica tape	Mica tape*
Binder insulation	Cotton tape Synthetic-fiber cloth tape	Asbestos tape Fiber-glass tape	Asbestos tape Fiber-glass tape
Slot sticks or wedges	Wood Fibre Paper or cotton laminate	Phenolic laminates (usually with asbestos or fiber-glass cloth)	Asbestos-silicone laminate Fiber-glass–silicone laminate
Lacing and tying cord (end-winding support)	Cotton twine Flax twine	Asbestos twine or sleeving Fiber-glass twine or sleeving	Asbestos twine or sleeving* Fiber-glass twine or sleeving*

* Treated or bonded with silicone resin only.

† Frequently coil-turn insulation suffices.

Conventional wedge materials are no longer permissible on electric machinery for Navy service. Flat slot wedges for all class A and B insulated motors should be glass-melamine laminated. Formed slot wedges made of fibre are acceptable on class A insulated motors.

For class B motor insulation any organic paper (for structural support of mica or mica-glass ground or end insulation) must be of minimum thickness, preferably not over 0.003 inch.

Usually form-wound coils are built up of rectangular conductors, but round wire may sometimes be used. The turn insulation may be enamel, cotton, or paper for class A windings, whereas for class B and H windings asbestos, mica, or fiber-glass insulation with suitable resin treatment is used. (Organic resin is used for class B, and silicone resin for class H.) The rectangular wire shape allows a more definite pattern to the turns of each coil. The coil is first wound by forming it into a loop or hairpin form. Often the slot portion of the coil is molded, and the coil then pulled or formed into the familiar hexagonal or "frog leg" forms. Sometimes the coil is formed before the slot part is bonded. The coils may then be taped all over with cotton, varnished cambric, or mica tapes. The slot portion may be insulated with a wrapper of fish paper, treated cloth, or mica. Coils are generally given one or more varnish treatments at one or more conditions of manufacture. The number of tapings or wrappings and varnish coats depends upon the voltage requirements, as does also the selection of untreated or varnished cloth tapes or mica products. The use of rectangular wire and accurately formed coils with a molded slot portion simplifies the winding of an open-slot motor. This winding procedure consists of inserting the coils in the proper slots with as tight a fit as possible, care being taken to avoid mechanical injury to coil insulation by impact or abrasion. Formed coils are held in place by wedges or steel bands or a combination (see Chap. 4).

Figure 3–3 lists the conventional kinds of insulations used in form-wound coils for d-c motor and generator armatures.

Figure 3–4 lists corresponding materials used in armatures for a-c motors and generators. Both charts list insulating materials according to standard temperature classifications.

3–3. SPECIAL REQUIREMENTS OF CLASS H WINDINGS

Class H insulated windings are significantly different from class A and B windings. The permissible operating temperatures for class A and B windings differ only by 25 degrees C, and both are usually baked at about the same temperature after varnish treatment. Class H windings have a permissible operating temperature 70 degrees C above that of class B and 95 degrees C above that of class A and should be baked at temperatures more than 50 degrees C higher than are ever used for class B. This necessitates avoiding organic components in class H coils and windings. Winders commonly employ many miscellaneous insulating materials (not specified by the designer) on conventional windings. This must be avoided on class H windings, as organic materials such as adhesive tape, glue, shellac, organic varnish, friction tape, cotton tying cord, and paper will be detrimental. These organic materials degrade during the high-temperature bakes or later during operation. This results in "gassing," which renders the insulation porous and susceptible to moisture attack. Figure 3–5 is a typical winding specification for a class H winding and describes the material requirements and special precautions necessary to ensure a high-quality level. Figure 3–6 shows how silicone insulation and materials can be used in typical motor construction.

3–4. COIL CONSTRUCTION

Armature Coils. All rotating electric machines employ armature coils (whether the armature is the rotor or the stator). Such coils have common insulation requirements

Fig. 3-5. Specifications for Rewinding A-c Induction Motors with Class H Insulation Based on Silicone Resins

(Extracted from "Silicone Notes," Dow Corning Corp.)

Materials

Only inorganic materials (glass, mica, asbestos, etc.) bonded and/or impregnated with silicone resins shall be used.

Requirements

Magnet Wire. The coils of these motors shall be made of double glass served silicone-bonded magnet wire.

Ground Insulation or Slot Liners. A glass-mica-glass composite bonded together with silicone resins or a silicone rubber-glass-silicone-resin combination shall be used for ground insulation.

Coil Separators. A glass-mica-glass composite bonded together with a silicone resin or a glass-silicone laminate (type GSG) or a silicone-rubber–glass–silicone-resin combination shall be used for coil separators.

Phase Separators. Silicone varnished glass cloth, a glass-mica-glass composite bonded together with a silicone resin, or a silicone-rubber–glass–silicone-resin combination shall be used for phase separators.

Tape. Where it is necessary to tape the coil noses of mush-wound coils, untreated glass tape shall be used. Preinsulated coils should be taped with silicone varnished glass tape, silicone-mica-glass tape, or silicone-rubber-glass tape.

Tying Cord. Only silicone-impregnated glass cord or untreated glass sleeving shall be used.

Sleeving. Only silicone varnished or untreated glass sleeving shall be used.

Slot Wedges. The slot wedges shall be made of glass-silicone laminate (type GSG).

Coil Connections. All coil connections or joints shall be made by brazing or by soldering with Silfos, Phos-Copper, or other solders which have a softening point of more than 285 C.

Coil Supports, Coil Wedges, Mechanical Supports. All items used for mechanical blocking shall consist of laminated or molded glass-silicone or asbestos-silicone materials.

Lead Wire. The lead wire shall consist of a stranded extra-flexible copper wire insulated with silicone rubber and covered with a glass braid.

Impregnating Varnish. The impregnating varnish shall be silicone varnish. Two or more coats of varnish shall be applied and baked in accordance with the varnish manufacturers' recommendations.

Sticking Varnish. Where it is necessary to use sticking varnish, silicone taping dope shall be used.

Potting or Calking Compound. The potting compound used to cement the motor leads in the motor terminal chamber shall be silicone rubber.

Paint or Enamel. The outside of the motor shall be painted with a silicone machinery enamel capable of withstanding continuous operation at 200 C.

All Other Components. Any other necessary components shall consist of silicone-glass, silicone-glass-mica, silicone-rubber–glass–silicone-resin combinations, or any other inorganic material capable of withstanding 200 C continuously.

Caution: No organic materials such as friction tape, scotch tape, organic sticking varnish, cotton tying cord, paper, etc., shall be used.

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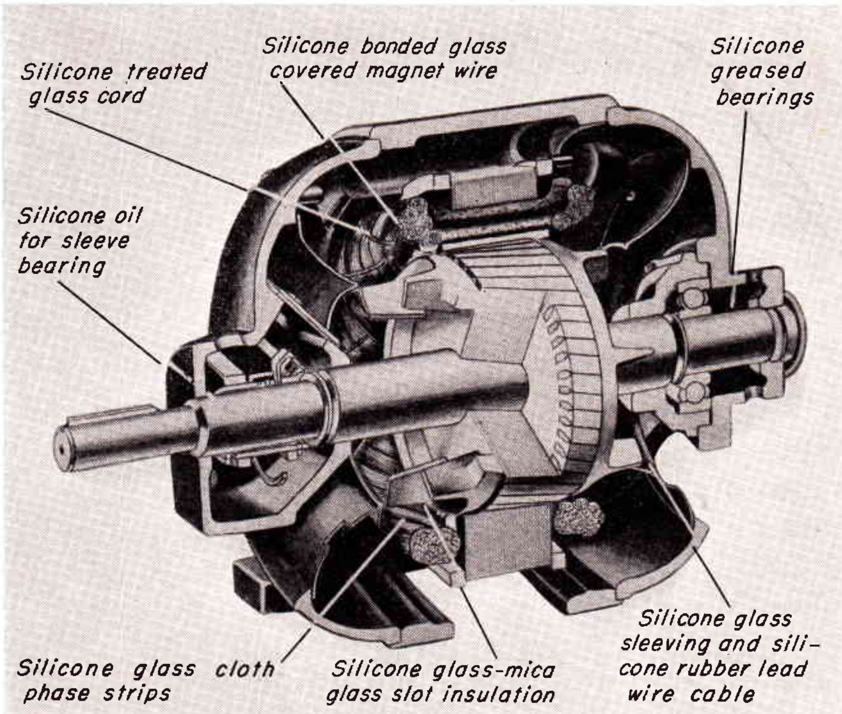
which differ in magnitude, depending upon operating voltage and service conditions. There are three basic kinds of insulation employed on such coils, namely, conductor insulation, ground insulation, and the binder or physical supporting insulation.

Field Coils. Many electric machines (though not all) contain field coils. These are generally multiturn coils wound in layers and sections. Here again the insulation may be divided into three classes: conductor, ground, and binder. However, some types of coils do not have so clearly identifiable classes of insulation application as do armature coils. Field coils can be subdivided into two broad classes.

1. Mummified coils are completely covered by tape which provides the ground insulation. This minimizes creepage problems but also impedes heat transfer and makes cooling difficult.

2. Coils with cell-type ground insulation include all others not mummified (where ground insulation is provided by cells, barriers, and blocks). Some coils of this construction are wound on poles, and others may be embedded in the iron of turbo-rotors. The principal distinguishing characteristic is that, while solid insulating barriers may be provided at some points of minimum clearance, there are numerous points where only creepage insulation is provided. Such coils usually have better



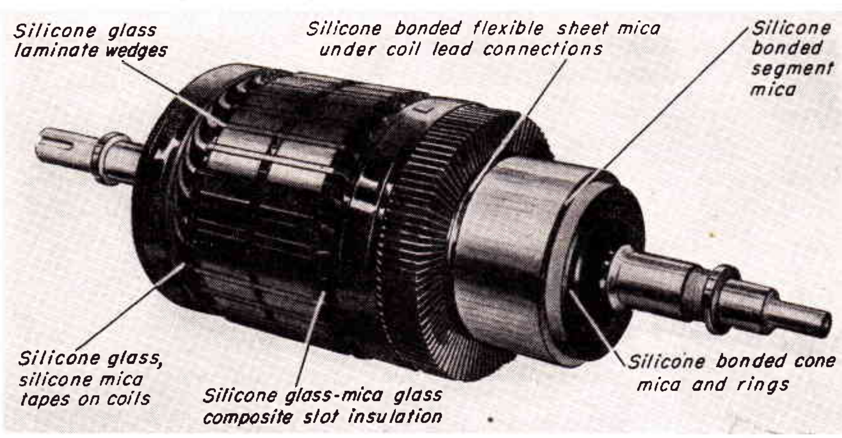
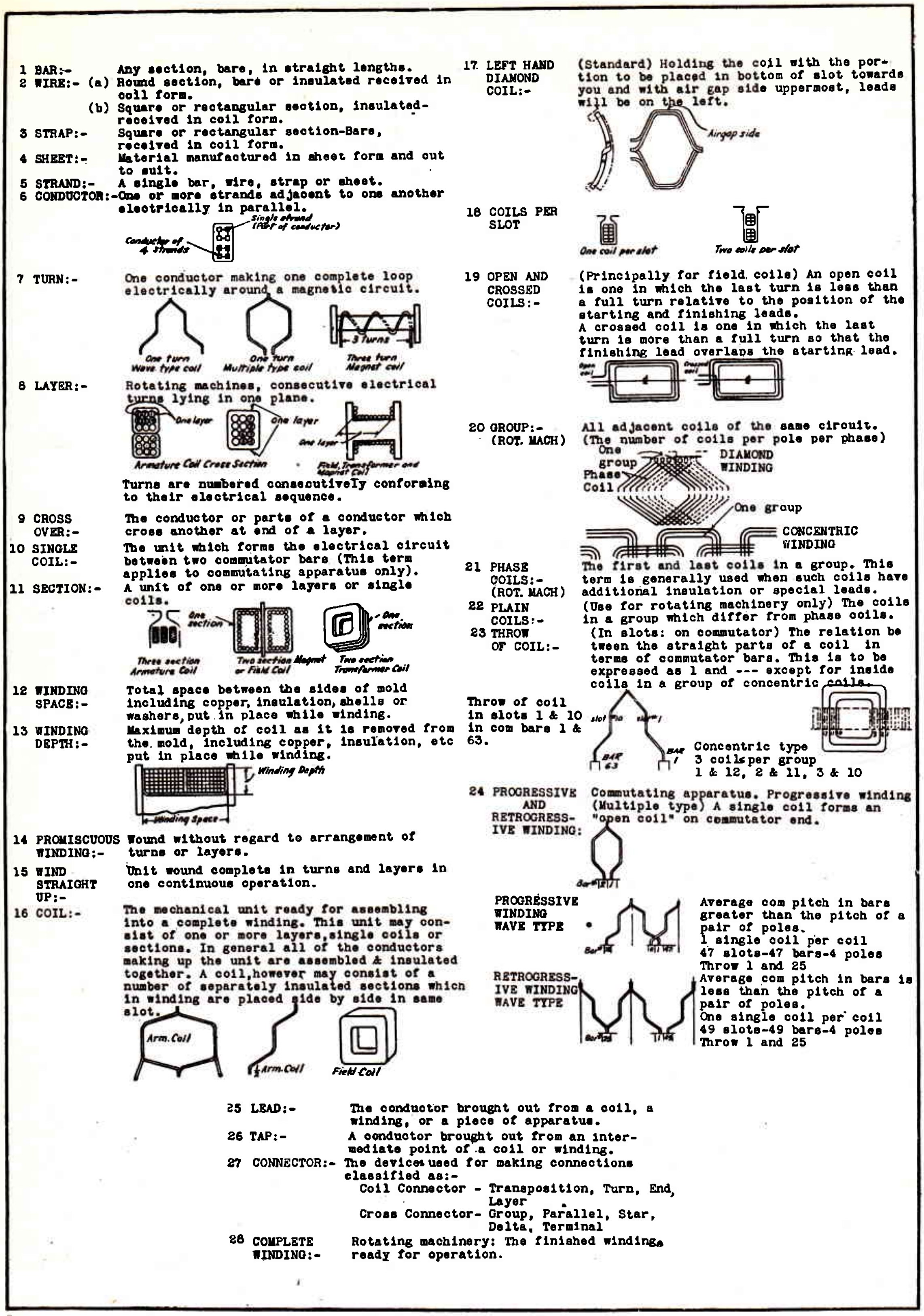


FIG. 3-6. How silicone insulation and materials can be used in motor construction. (*General Electric Co.*)



1 BAR:- Any section, bare, in straight lengths.

2 WIRE:- (a) Round section, bare or insulated received in coil form.
(b) Square or rectangular section, insulated-received in coil form.

3 STRAP:- Square or rectangular section-Bare, received in coil form.

4 SHEET:- Material manufactured in sheet form and cut to suit.

5 STRAND:- A single bar, wire, strap or sheet.

6 CONDUCTOR:- One or more strands adjacent to one another electrically in parallel.

7 TURN:- One conductor making one complete loop electrically around a magnetic circuit.

8 LAYER:- Rotating machines, consecutive electrical turns lying in one plane.

Turns are numbered consecutively conforming to their electrical sequence.

9 CROSS OVER:- The conductor or parts of a conductor which cross another at end of a layer.

10 SINGLE COIL:- The unit which forms the electrical circuit between two commutator bars (This term applies to commutating apparatus only).

11 SECTION:- A unit of one or more layers or single coils.

12 WINDING SPACE:- Total space between the sides of mold including copper, insulation, shells or washers, put in place while winding.

13 WINDING DEPTH:- Maximum depth of coil as it is removed from the mold, including copper, insulation, etc put in place while winding.

14 PROMISCUOUS WINDING:- Wound without regard to arrangement of turns or layers.

15 WIND STRAIGHT UP:- Unit wound complete in turns and layers in one continuous operation.

16 COIL:- The mechanical unit ready for assembling into a complete winding. This unit may consist of one or more layers, single coils or sections. In general all of the conductors making up the unit are assembled & insulated together. A coil, however may consist of a number of separately insulated sections which in winding are placed side by side in same slot.

17 LEFT HAND DIAMOND COIL:- (Standard) Holding the coil with the portion to be placed in bottom of slot towards you and with air gap side uppermost, leads will be on the left.

18 COILS PER SLOT

19 OPEN AND CROSSED COILS:- (Principally for field coils) An open coil is one in which the last turn is less than a full turn relative to the position of the starting and finishing leads.
A crossed coil is one in which the last turn is more than a full turn so that the finishing lead overlaps the starting lead.

20 GROUP:- (ROT. MACH) All adjacent coils of the same circuit. (The number of coils per pole per phase)

21 PHASE COILS:- (ROT. MACH) The first and last coils in a group. This term is generally used when such coils have additional insulation or special leads.

22 PLAIN COILS:- (Use for rotating machinery only) The coils in a group which differ from phase coils.

23 THROW OF COIL:- (In slots: on commutator) The relation between the straight parts of a coil in terms of commutator bars. This is to be expressed as 1 and --- except for inside coils in a group of concentric coils.

24 PROGRESSIVE AND RETROGRESSIVE WINDING: Commutating apparatus. Progressive winding (Multiple type) A single coil forms an "open coil" on commutator end.

PROGRESSIVE WINDING WAVE TYPE — Average com pitch in bars greater than the pitch of a pair of poles.
1 single coil per coil
47 slots-47 bars-4 poles
Throw 1 and 25

RETROGRESSIVE WINDING WAVE TYPE — Average com pitch in bars is less than the pitch of a pair of poles.
One single coil per coil
49 slots-49 bars-4 poles
Throw 1 and 25

25 LEAD:- The conductor brought out from a coil, a winding, or a piece of apparatus.

26 TAP:- A conductor brought out from an intermediate point of a coil or winding.

27 CONNECTOR:- The devices used for making connections classified as:-
Coil Connector - Transposition, Turn, End, Layer
Cross Connector- Group, Parallel, Star, Delta, Terminal

28 COMPLETE WINDING:- Rotating machinery: The finished winding, ready for operation.

FIG. 3–7. Winding terms and definitions. (*Courtesy of Westinghouse Electric Corp.*)

heat-dissipation characteristics but are more susceptible to humidity and surface dirt than mummified coils.

3–5. MATERIAL SELECTION

The problem of selecting insulating materials is very broad and complex. This discussion will outline principles and objectives in relation to the various types of coil construction. In many cases it becomes necessary to use examples and illustrations by describing conventional practice. In most cases there are several materials from which to choose for any application, and the one selected will depend upon many factors, such as the following:

1. Temperature classification.
2. Mechanical characteristics desired.
3. Dielectric strength requirements.
4. Special conditions encountered, such as unusually severe moisture, chemical contaminants, abrasive atmosphere, and fungus growths encountered in the tropics.

Following is a brief summary of the kinds of materials frequently used for each application.

1. "Conductor insulation" between strands and turns may be any of the following depending upon specific requirements.

a. Enamel.
b. Paper.
c. Cotton.
d. Silk.
e. Asbestos.
f. Fiber glass—continuous filament, sliver or woven tape.
g. Mica tape.

2. "Ground insulation" is the basic insulation between winding and core and is of vital importance, as it must withstand full operating voltage for the life of the winding as well as overpotential tests for short periods of time. For this purpose the following materials are commonly used:

a. Varnish-treated cloth (wrapper).
b. Fish paper and treated cloth (as slot cell).
c. Fish paper and mica (both as wrapper and slot cell).
d. Paper-backed mica wrapper.
e. Glass-backed mica wrapper.
f. Continuous mica tape.
g. Molded mica cells.
h. Fabricated cells employing laminated and molded materials.

Note. On large or important apparatus mica is generally considered essential as the basic ground insulation regardless of temperature classification except on low-voltage windings.

3. Binder tapes are for structural and finishing purposes only. Although their function is more mechanical than electrical, they do furnish the basis for the final waterproofing coating provided by the varnish treatment. Materials in common use include:

a. Cotton tapes.
b. Fiber-glass tapes.
c. Asbestos tapes.
d. Synthetic-resin fabric tapes.

4. Varnishes are a vital part of the insulation of electric machines. They are used to fill or impregnate the insulation voids and to coat the surfaces of electric equipment so as to increase the resistance of the insulation to penetration of moisture, dirt, and foreign materials. They also minimize the effect of conducting compounds and particles on exposed creepage surfaces. In addition varnishes fill important physical needs. In wound apparatus they produce adhesion of windings or coils in slots and provide rigidity in the insulation and windings to withstand mechanical

FIG. 3–8. TYPICAL CLASS A AND B INSULATING MATERIALS APPLIED TO A-C MOTORS OF 2,300-, 4,000-, AND 7,000-VOLT RATINGS

(Courtesy of Fairbanks, Morse & Co.)

	Voltage rating					
	Class A			Class B		
	2,300	4,000	7,000	2,300	4,000	7,000
Lead taping	Two layers of half-lapped 0.007-in. cotton tape	Three layers of half-lapped 0.007-in. cotton tape	Two layers of half-lapped 0.007-in. varnished cloth tape and one layer half-lapped 0.007-in. cotton tape	One layer of triple-lapped 0.005-in. mica tape and one of half-lapped 0.005-in. fiber-glass tape	Two layers of half-lapped 0.005-in. mica tape and one of half-lapped 0.005-in. fiber-glass tape	Two layers of triple-lapped 0.005-in. mica tape and two of half-lapped 0.005-in. fiber-glass tape
Wrapper	2⅓ turns of 0.007-in. varnished cloth	3⅓ turns of 0.007-in. varnished cloth	Two wrappers of 3⅓ turns each 0.007-in. cloth	2⅓ turns of 0.010-in. varnished fiber-glass cloth	3⅓ turns of 0.010-in. glass-backed mica	4⅓ turns of 0.015-in. glass-backed mica
End taping	Two layers of triple-lapped 0.007-in. cotton tape	One layer of half-lapped 0.007-in. varnished cloth tape and two layers of triple-lapped 0.007-in. cotton tape	Two layers of triple-lapped 0.007-in. varnished cloth tape (one over each wrapper end) and one layer of half-lapped 0.007-in. cotton tape	Two layers of half-lapped 0.005-in. mica tape and one layer of half-lapped 0.005-in. fiber glass	Two layers of triple-lapped 0.005-in. mica tape and one layer of half-lapped 0.005-in. fiber-glass tape	Four layers triple-lapped 0.005-in. mica tape (two under and two over the leads) one layer over each wrapper end. Two extra layers on corners
Outside coil taping	One layer of half-lapped 0.007-in. cotton tape on slot section			One layer of half-lapped 0.005-in. fiber-glass tape on slot section		

shock. In some equipment, proper filling of internal voids with varnish resins promotes better heat dissipation. Filling of voids and proper sealing of the equipment surfaces greatly increase insulation life and thereby the life of the machine. Varnishes and the processes for their application are discussed at length in Chap. 5.

3–6. BASIC REQUIREMENTS FOR GROUND INSULATION

As has been stated earlier, insulation "insulates" in three different ways. The insulation between two conductors can support a dielectric stress (1) when separated by a fluid dielectric, (2) when separated by creepage spacing over a surface or through a porous material, and (3) when separated by a dielectric barrier. In the second case the voltage that can be supported by creepage is widely variable, being dependent very largely on humidity conditions and contamination of the surface or pores of the separating material. In this case breakdown under certain conditions may be a conduction phenomenon and may occur at extremely low voltages. The factor of safety is necessarily quite high for creepage insulation. Where such insulation is used between winding and ground or between different circuits, the allowances made should be approximately according to Fig. 4–6. The spacing required is usually too great for use within armature slots or inside commutators. It is preferable to use a dielectric barrier for ground insulation, as such barriers possess intrinsic dielectric strength well above the creepage spacing strength that can be designed into cramped space even when the creepage surface is kept clean and dry. A true dielectric barrier will be far less affected by moisture, oil, dirt, and chemical contaminants than creepage insulation will be. The existence of a dielectric barrier can be demonstrated only by applying a proof test voltage which is well above the breakdown of the equivalent air spacing between conductors.

3–7. APPLICATION OF INSULATING TAPES

The complex shape of coils generally requires hand taping, as automatic machine taping is usually applicable only to wire and strap. This involves a great deal of manual labor requiring considerable skill and manual dexterity. An experienced taper gives the appearance of working swiftly and easily without effort. Labored application of tape is apt to be indicative of inexperience, which may result in a poor job. Insulating tapes can be applied in several ways as follows:

1. *Spaced.* Here the adjacent convolutions of tape do not quite touch in most places although they may occasionally touch at spots. This is a rapid, low-cost procedure.
2. *Butted.* Tape applied in this manner is intended to give a smooth, even appearance without openings and necessitates careful workmanship which involves more time than spaced tape.
3. *Overlapped.* Tape is applied in a lapped spiral so that there is at least one thickness of tape at all points with a minimum overlap equal to one-third of the tape width. It is usually inadvisable to attempt to apply tape more than half lapped. From the point of view of space conservation, tape should be just slightly less than half lapped.

It is a relatively simple matter to apply tape by one of the foregoing methods to a straight uniform section. However, most coils are not straight or uniform throughout their whole length. This necessitates the exercise of considerable care, with skill and training, to apply the tape smoothly in such a manner that the true objective of the insulation will be attained. Operators must guard against "camouflaging" a coil instead of insulating it. The two cannot be distinguished by visual observation after the product is complete. Where insulating tapes are applied for barrier action, it is

important that the tape be adequately lapped at the point of greatest periphery of the coil even though this results in excessive lapping on the shorter periphery. It is sometimes permissible to reduce the width of the tape at the shorter periphery by trimming it with scissors as each turn is applied. Here again care and skill must be exercised to be sure that the tape is not trimmed excessively and that a satisfactory lap of the tape is obtained at every point between adjacent turns of tape.

Tape applied as an insulating barrier is almost invariably overlapped, and this is usually specified as "half lapped."

Internal binder tapes are frequently spaced.

Surface-finishing tapes are usually butted on the slot part (to save space) and overlapped on the coil ends.

3–8. TURN INSULATION

Turn insulation of armature and field coils is generally provided by some standard form of wire covering such as enamel, cotton, silk, asbestos, or fiber glass. In the larger and special wire sizes, mica tape may be applied directly to the strap before it is formed into an armature coil. Where the shape of an armature coil is of such a nature that the turn insulation may be damaged in the forming, it may be necessary to patch the wire covering in order to reinforce it at the points where forming damage has occurred. On some special coils of unusual shapes, the bare copper may be formed to shape before the insulation is applied. In such cases it is common to use mica tape for the turn insulation although glass-fiber or even cotton tape may be used if the thermal and voltage requirements will permit.

3–9. ARMATURE–COIL GROUND INSULATION

The ground insulation for armature coils must withstand preliminary overpotential tests as well as the operating voltage between the windings and the core of the machine. It can generally be assumed that the core and frame of the machine are at ground potential, although not all machines are operated with their frames solidly grounded. When frames are operated ungrounded, there is generally less dielectric stress between the winding and core than the total voltage to ground. Therefore, it is a safe assumption to provide sufficient insulation to withstand the full voltage to ground, but the test voltage need not be so high. On d-c machines there are only two opposite potentials and therefore no phase relationship, such as exists on a-c machines. On a-c machines, particularly three-phase windings, the frame is usually at an intermediate voltage with respect to the terminals of the windings. On a three-phase winding with the neutral grounded the voltage from each terminal to ground will be 57.7 percent of the terminal-to-terminal voltage. This fact is usually disregarded in establishing insulation levels for windings, as it is customary to use merely the line voltage in determining the insulation voltage class.

Very low voltage machines may seem to require little more than positive separation between the windings and the core when no moisture is present. Thus the thinnest piece of paper or fabric without treatment may be adequate insulation **as long as it can be kept dry**. Reference to Paschen's law (Fig. 1–3) indicates that, as long as there is any positive separation between two conductors, at least 335 volts will be required to break down the air space. This is 335 volts dc or 335 peak volts ac which is 237

a-c rms volts. Thus it can be seen that apparatus operating at 220 volts ac and below may not need a solid dielectric barrier between windings and core for normal operation **when clean and dry.** The need for such a barrier arises from the requirement that it meet the initial overpotential tests and to ensure reliability under adverse humidity conditions. The ability of a winding to pass its initial overpotential tests could be met by merely adding thicknesses of untreated paper or cloth, **but this would not provide reliability under exposure to dirt and moisture during operation.** To provide such positive assurance of satisfactory operation a **true dielectric barrier must be used as ground insulation** as recommended in Sec. 3–7. From this it can be seen that it is a mistake to place undue reliance on the mere fact that a winding has withstood a certain standardized proof test unless the construction of the basic ground insulation is known.

The ground insulation of armature coils can be in the form of a slot cell or a wrapper. Slot cells are normally employed on the so-called "mush-wound" or "random-wound" armatures and stators where the armature coil itself has no separate entity. In such cases the ground insulation in the form of a slot cell is applied directly to a core, and the winding is placed into it slot by slot. On form-wound armature coils, "wrapper" type ground insulation is commonly used. The wrapper may consist of varnished cloth, varnished paper, composite mica, or some form of synthetic resin sheet. The wrapper is applied to the straight part (or slot section with suitable creepage extension) of the coil in a single sheet with multiple turns around the coil. It is usually specified as "one and one-half,"

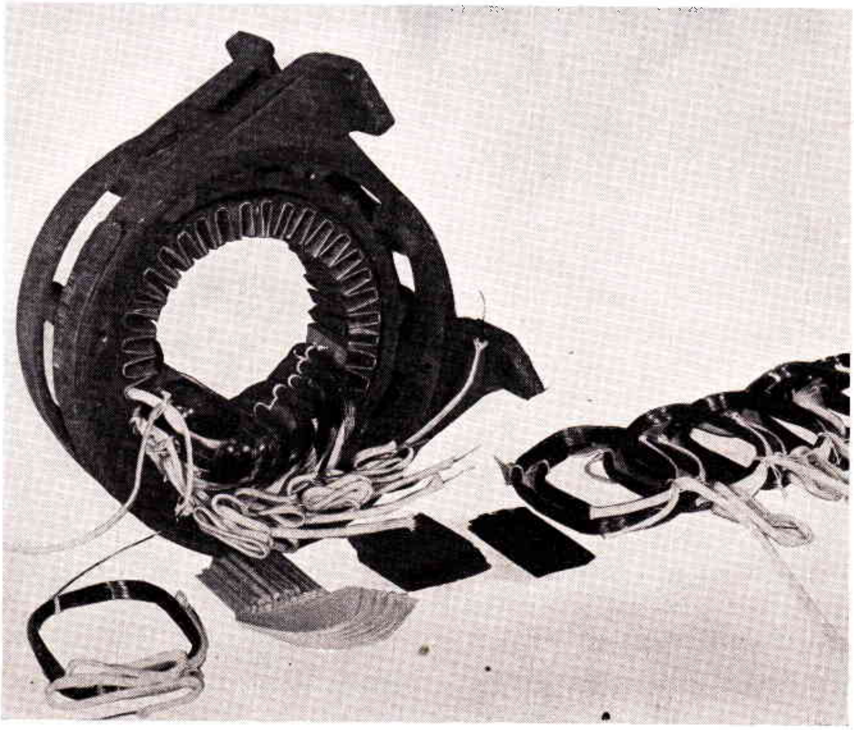


FIG. 3–9. Random winding. (*Fairbanks, Morse & Co.*)

"two and one-half," etc., turns. Others refer to wrappers as "one and one-third," etc., turns with a similar meaning. The "half turn" or "one-third turn" merely indicates more than one, two, etc., and that the wrapper edges are overlapped, usually on one of the flat sides. Frequently coils employing wrappers as the ground insula-

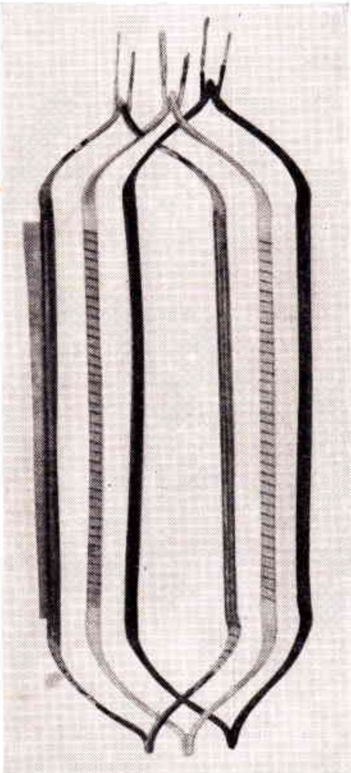


FIG. 3–10. Form-wound armature coil. (*Elliott Co.*)

tion will have end-turn insulation consisting of one or more half-lapped layers of tape such as treated cloth or mica.

In the lower voltage class (250 volts and below) it is quite common to use treated paper, varnish-treated cloth, combinations of fish paper and varnished cloth as well as one of a variety of composite mica sheets as ground insulation. In the smaller sizes of these motors, especially those which are random wound of round wire, it is common

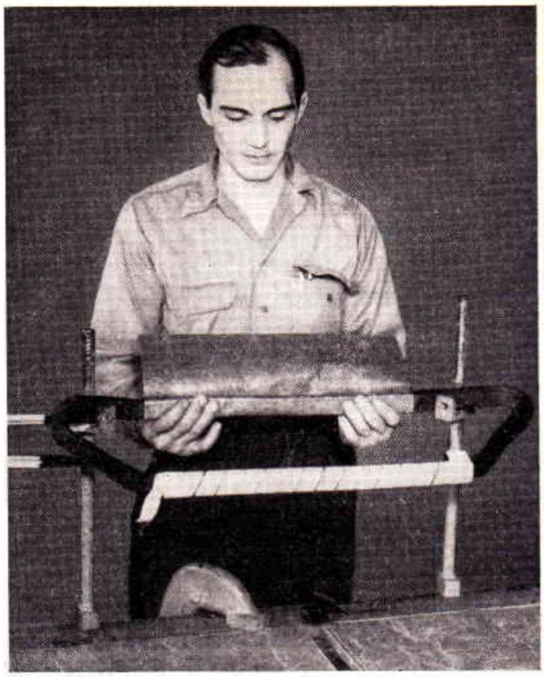


FIG. 3–11. Application of wrapper to armature coil. (*Elliott Co.*)

practice first to place the ground insulation into the slot as a cell (with suitable creepage extension) and to wind the conductors into this cell. On larger sizes with preformed coils, the ground insulation is more commonly applied as a wrapper wherein one or

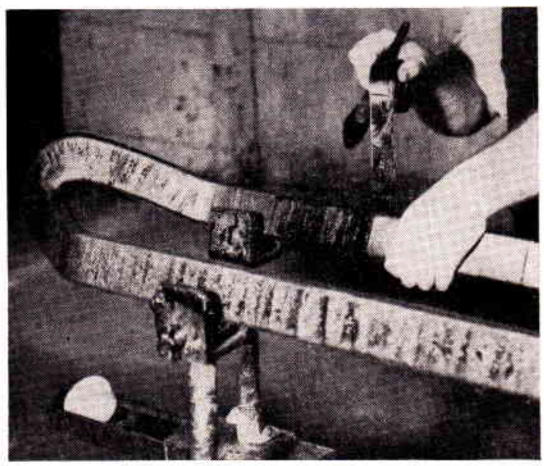


FIG. 3–12. Application of continuous mica tape as ground insulation. (*General Electric Co.*)

more turns of insulating sheet are wrapped around the straight section of the armature coil. Wrapper-type insulations are used as high as the 6,900-volt class but are seldom used on machines of higher voltage classification.

Taped insulations, especially those employing mica tape, are used for ground insulation on all voltage classes. They are particularly well suited to the higher voltage classes, especially for the larger motors and generators. This type of insulation is usually applied continuously in multiple layers completely around the whole coil, extending over both the slot section and the diamonds as a continuous sheath. Continuous mica-tape insulation has the particular advantage of eliminating the joint between the insulation of the slot section and the insulation of the coil ends or diamonds. In the higher voltage windings it is particularly necessary to provide insulation protection between adjacent coils in the diamonds, where full terminal-to-terminal voltage may exist between coils of different phase groups.

3–10. FIELD-COIL CONSTRUCTION

There are a number of general types of field coils depending upon the size of wire from which they are wound and the general size and shape of the coils.

1. Fine-wire coils employing small round enameled, cotton-covered, asbestos-covered, glass-covered, or similar wire are frequently wound in a more or less random fashion, as it is quite difficult to obtain even layers of the smaller wires. In the larger round-wire sizes it is easier to maintain even layers.

2. Rectangular or square wire makes solid construction of field coils, as the wire naturally winds in even layers in a very regular fashion.

3. Bare copper strap is frequently wound flat in "pancakes" with some form of flat tape insulation between turns. These pancakes can then be connected in groups to form a composite field coil. Sometimes after one pancake is wound, it is reversed and a second similar pancake wound alongside after brazing the wire to the stub end of the first section. In coils of this sort the

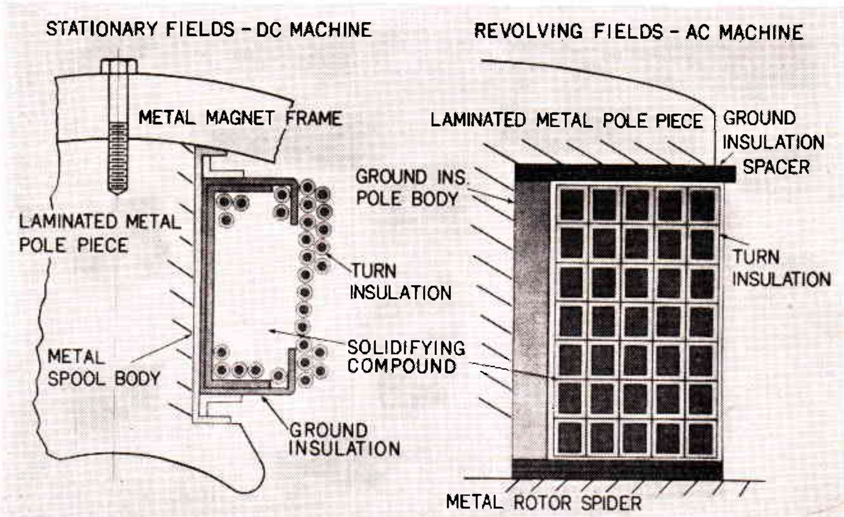


FIG. 3–13. Cross section of field coils with round and rectangular wire. (*General Electric Co.*)

tape insulation between turns extends $\frac{1}{32}$ to $\frac{1}{16}$ inch beyond the edge of the strap to provide some slight additional creepage. Insulating washers of asbestos and mica sandwiches are quite commonly used for insulation between pancake sections.

4. Edge-wound coils are usually those which have the heaviest section of copper. The coils are usually wound from bare copper on very large winding machines. After the turns have been formed, it is usually necessary to press out the copper bulges at the corners and then to anneal the copper before any insulation is applied. For turn insulation on edge-wound coils the most common material is paper. Generally two thicknesses of about 0.007-inch-thick paper are employed. Wood pulp paper is used for class A, and asbestos paper for class B. The paper is usually pretreated with some resinous bond, and frequently the turns of the coil are also coated with a similar resinous bond. Shellac is quite a satisfactory treating and bonding material, although many synthetic resins are also employed. After the paper has been placed between the turns of the coil, the coil is then heated electrically and placed under very high pressure. The coils are then generally clamped to the final pressed size, removed from the press, and allowed to cool while still clamped.

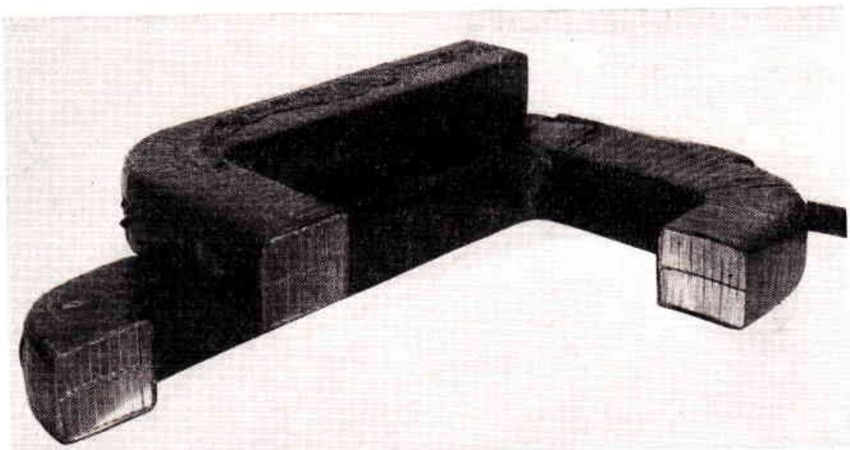


FIG. 3–14. Cross section of field coil flat wound of strap in pancakes. (*Fairbanks, Morse & Co.*)

3–11. MUMMIFIED FIELD COILS

Any of these types of field coils is suitable for the application of a completely enclosing insulation in tape form. Coils with this type of insulation are frequently called "mummified." When this type of insulation is employed, one or more layers of tape are applied over the whole coil surface and overlapping the leads to provide adequate creepage at the points where the leads leave the coil. The tape may be cotton, glass, or mica tape with a finishing layer of glass, cotton, or asbestos tape. The voltage and service conditions will determine the exact nature of the insulation and the thickness of the insulation wall. Coils of this type are generally impregnated by vacuum-pressure methods to obtain good fill of the insulation wall and coil interstices.

3–12. CELL-INSULATED FIELD COILS

Cell-type insulation may also be applied to any of the several kinds of field coils. Where the coils are completely insulated before being placed on poles, the cell-type

insulation may take one of a number of forms, such as the following:

1. Molded cells or spools may be applied after mold winding, or the coil may have been wound directly in such form.

2. Molded mica sheet is cut and formed and the joints staggered and lapped so as to provide a complete barrier where the coil is in contact with the pole and frame. To provide additional creepage up the coil sides it is quite common to break open the last few turns at either end of the coil and to tape these with mica tape, re-pressing and bonding the coil after this tape and the cell are applied.

3. Some field coils may be insulated with spacing blocks which provide creepage only. This is especially true where it is desired to have a great deal of cooling air circulate around the bare copper. This type of insulation is particularly applicable to edge-wound heavy strap coils such as illustrated in Fig. 3-15.

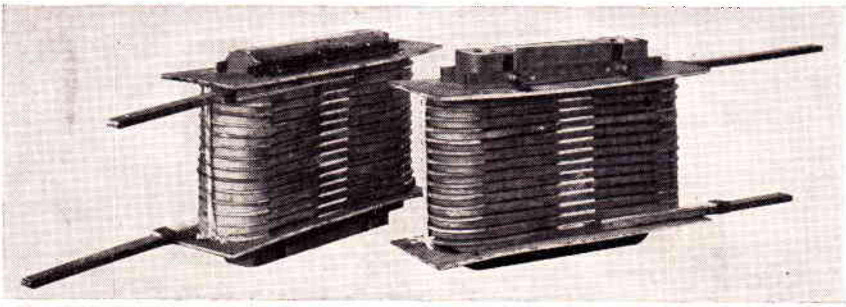


FIG. 3-15. Edge-wound field coil. (*Reliance Electric & Engineering Co.*)

4. A turbine-generator field is a special form of field coil wherein the turns are wound directly into the slots in the forged-steel rotor as shown in Fig. 3-16. Insulation between copper and iron is provided by molded mica slot cells. Turn insulation consists of mica tape similar to other flat-wound field coils. The top few turns may

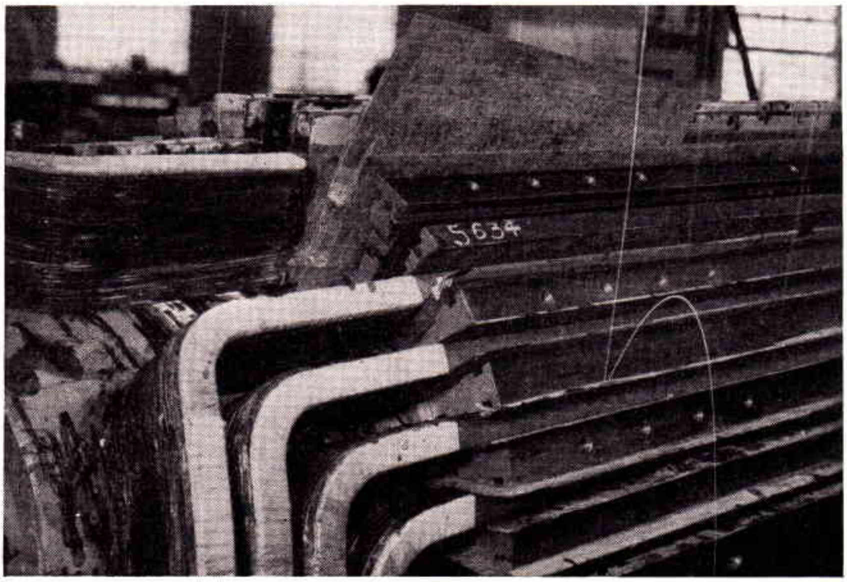


FIG. 3-16. Turbine-generator field construction and insulation. (*Elliott Co.*)

be mica taped (as in edge-wound coils) to obtain more creepage.

3–13. FIELD–COIL USAGE

Field coils should be classified as to usage as well as according to construction. They can be classified as shunt fields, series fields, and commutating (or interpole) fields.

Shunt fields are usually wound of relatively fine wire. They are frequently wound on forms which may be insulating spools or built-up tubes and washers. Sometimes they may be wound on forms with a varnish brushed between layers which is solidified by baking to provide the mechanical support. Sometimes they may be wound in separate sections with spacers between the sections to permit better circulation of air.

Series field coils usually employ much heavier wire than shunt coils and are frequently wound of heavy strap. They are frequently edge wound of bare copper with insulation only between the adjacent turns on the flat sides of the conductors. This exposes bare copper to cooling air, which greatly facilitates heat dissipation. Series coils may be used separately or in combination on the same pole with shunt coils where some degree of compounding or stabilizing of the magnetic field is desired.

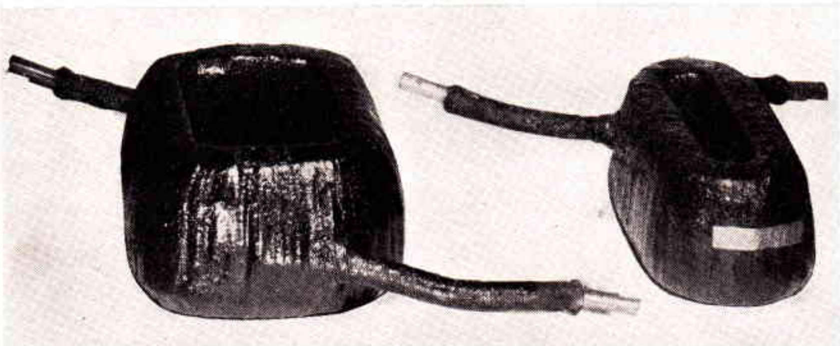


FIG. 3–17. Mummified field coil. (*General Electric Co.*)

Commutating (or interpole) field coils are frequently quite similar to series coils, as both are connected electrically in series with the armature winding of the machine. These, too, are frequently edge-wound copper strap.

The insulation of all field coils is generally somewhat similar within a particular d-c machine. On the lower voltages spools or shells are used for ground insulation. At higher voltages mummified field coils employ mica-taped ground insulation over the complete coil surfaces. Many of the larger field coils, particularly edge-wound strap, employ a molded mica shell which is formed onto the coil after it is completely insulated between turns. In order to provide creep-

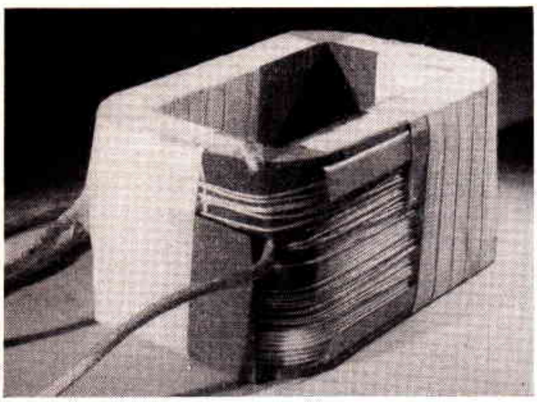


FIG. 3–18. Field coil with cell-type insulation. (*Westinghouse Electric Corp.*)

age to ground on the end turns, these turns are insulated as a group with layers of mica tape. On a-c machines field coils are frequently wound on poles, in which case the ground insulation is first applied to the pole and then the coil is wound onto it.

3-14. HIGH-VOLTAGE ARMATURE COILS

Modern turbine-generator armature coils employ stranded conductors in order to reduce eddy-current loss within the copper. High-capacity machines would have such large single conductors that the eddy-current losses would be excessive if the conductors were not stranded. On smaller turbine-generators the strands may not be transposed within the slot and the strand lying in the bottom of one end of the slot will also be at the bottom at the other end of the slot. However, on very long core machines, flux leakage will result in voltage differences between top and bottom conductors within a slot such as to produce excessive circulating current within a single turn. To overcome this it is necessary completely to transpose the conductors within the slot. This is accomplished by means of the Roebel transposition, which is shown in Fig. 3-19. In this form of transposition each conductor successively occupies every possible slot position as it is transposed. Additional transposition from slot to slot is accomplished by dividing the multiple strands of a turn into transposition groups. These groups are then transposed from slot to slot so that the group which comes out at the bottom of one slot may go in at the top or middle of the coil in the next slot. All strands must be insulated, and the transposed groups of strands must be insulated even though all constitute a single turn. Individual strand insulation is accomplished by employing conventional wire coverings such as cotton, asbestos, or glass fiber as well as mica-taped strap. Transposed groups are usually given the same type of insulation as turns which normally would be one or more half-lapped layers of mica tape.

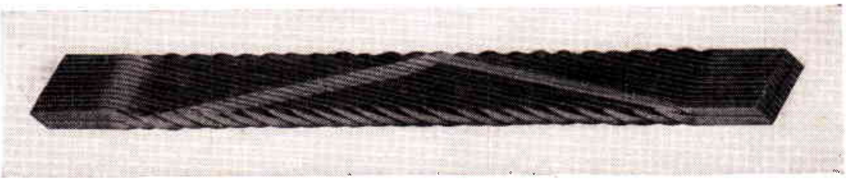


FIG. 3-19. Turbine-generator armature coil with Roebel transposition. (*Westinghouse Electric Corp.*)

Turbine-generator stator coils are frequently one-turn coils and because of their

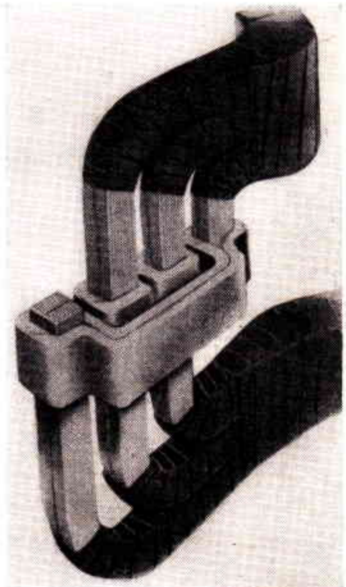


FIG. 3-20. Armature coil for high-voltage motor or generator with transposed group of conductors. (*Westinghouse Electric Corp.*)

size are made as bars or half coils with connections at both ends of the core. When the coil is assembled, it is usually bonded within the slot section by the application of some thermosetting type of varnish which is heated and pressed to size. The coil ends are formed on a former, and subsequently the ground insulation is applied. Modern high-voltage turbine-generator armature coils are usually insulated with continuous mica tape. This is applied continuously from end to end of a half coil. After a number of layers of tape have been applied, the coils are vacuum dried, impregnated, and then pressed to obtain consolidation of the ground wall and eliminate voids. Most manufacturers use an asphaltum compound for impregnation of this type of coil. After the ground wall is built to the required size, the finishing tape is applied. Finishing tapes may be cotton, asbestos, or glass fiber. Usually a special resin treatment is applied to the fiber-glass tape which differs from the impregnating material used for the mica tape.

During 1950 a new type of high-voltage insulation was developed for turbine-generator stator windings. This employs a continuous mica tape with synthetic resin bond and a heat-reactive solventless synthetic resin impregnant. Excellent filling of insulation voids is obtained. The composite insulation has low power factor, high dielectric strength, and greatly improved voltage endurance. The resin impregnant reacts into a solid resilient bond which is strong and has good elastic properties. This new insulation is particularly well adapted to very long turbine generators, where thermal cycling produces differential expansion of copper, iron, and insulation which results in serious deformation of the insulation. This new insulation is capable of elastic deformation to compensate for this movement. It provides a restoring force in the insulation wall to return the mica flakes to their normal position after each thermal cycle. It also has good thermal stability and excellent resistance to oil and moisture.

Armature coils for high-voltage motors and generators are frequently quite similar in many respects to turbine-generator coils. The essential differences are that the coils are generally multiturn rather than oneturn and may not be transposed within each slot. Transposition groups are employed as in large turbine generators, but generally the conductors are small enough that no strand transposition is required within each slot. Turn insulation consists of one or more layers of mica tape. Multiturn coils are frequently of the pulled type. The coils are pulled or formed before the turn insulation is applied to groups of conductors. The coils are then bonded in the slot part, and the ground insulation applied. Coils above the 6,900-volt class nearly always employ continuous mica-tape insulation as used on turbine generators, and many machines as low as 2,500 volts employ continuous mica-tape insulation.

3-15. ESTIMATING INSULATING SPACE AND DIELECTRIC STRENGTH

Practices of various manufacturers differ as to space allowance for the ground insulation wall on armature coils. Also the requirements of different industries and service conditions may vary so as to prevent any specific statement as to the proper space to allow for insulation as a function of voltage. However, the basis for such allowances can be stated in an empirical formula. The actual value of the constants depends upon the judgment of the designer and types of materials employed. Usually machinery for marine service is conservatively designed with a high factor of safety.

$$t = E \times M + C$$

where t = thickness of ground wall (average for one side), inches.
E = rated voltage of the machine.
M = multiplier for the particular application.
C = constant for the application.

For a great number of actual insulation studies C ranges from 0.015 to 0.075 where M ranges between 0.7×10^{-5} and 3×10^{-5} for t values in inches.

To illustrate the use of this formula the following case was chosen:

$$E = 750 \text{ volts}$$
$$M = 2 \times 10^{-5}$$
$$C = 0.025$$

Therefore,

$$t = 750 \times 2 \times 10^{-5} + 0.025$$
$$= 0.040 \text{ inch average ground wall (one side)}$$

Selecting a practical and available combination of materials, the insulation wall thickness and suitability are checked as follows:

1. *Materials.* *a.* Mica wrapper 0.010 inch thick having a minimum 1-minute dielectric strength of 5,000 volts (a-c rms).

b. Fiber-glass binder tape 0.007 inch thick for finishing.

c. Varnish treatment of finished coil.

2. *Size Calculation.*

	Double Wall Thickness
Five thicknesses of 0.010 mica (2½ turns)	0.050
Two layers (butted) of 0.007 fiber-glass tape	0.014
Allowance for varnish treatment	0.010
Allowance for material variation	0.006
Total insulation (double wall)	0.080

Therefore, single wall-insulation thickness is 0.040.

3. *Dielectric-strength Estimates.* One thickness has a minimum 1-minute dielectric strength of 5,000 volts, so two thicknesses on a coil will have an approximate strength of at least 2 × 5,000 × 75 percent, or 7,500 volts (allowing for 25 percent deterioration in handling and winding). The final test (see Chap. 6) on a 750-volt winding would be twice normal plus 1,000 (2 × 750 + 1,000), or 2,500 volts. The preliminary momentary test would be about 35 percent higher, or 3,400 volts. Such a coil having at least 7,500 volts' intrinsic dielectric strength should easily stand both the preliminary test and the final test. However, had a one and a half turn wrapper been used instead of a two and a half turn wrapper the dielectric strength would have been marginal (3,750 volts to withstand a preliminary test of 3,400 volts) at a saving of only 0.010 inch per side out of an average of 0.040 inch.

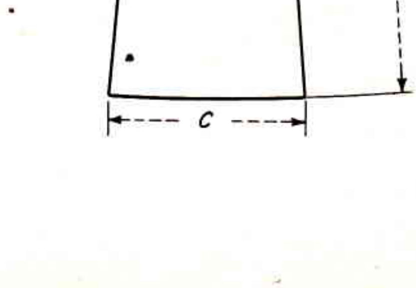
3–16. CALCULATING COILS FOR RANDOM WINDINGS

The number of insulated wires that may be wound in the core of an induction motor with partially closed slots can be estimated as follows:

Determine the available space (S) from the following formula:

$$S = [A - (E + I_d)] \times \left(\frac{B + C}{2} - I_w\right)$$

where S = available space, square inches.
A = depth of slot.
B = width of slot at top.
C = width of slot at bottom.
E = tooth lip thickness.
I_d = insulation allowance depthwise.
I_w = insulation allowance widthwise.



TYPICAL ALLOWANCE FOR I_d AND I_w

Coil sides per slot	I_w	I_d
1	0.08	0.19
2	0.08	0.24
4	0.09	0.29

Then the coil space factor will be:

$$\text{Percent coil space factor} = \frac{100 \times D^2 \times N}{S}$$

where D = insulated diameter of the wire, inches.
N = number of wires per slot.
S = available space in slot (see above).

Although it is possible to wind coils up to 100 percent space factor, the practical limit is in the range of 80 to 85 percent. This varies with wire size, core length, slot shape, throw of coils, and tightness of coils in ends.

Coil Length and Coil Extension. For small induction motors the coil-winding length and end-winding loop can be approximated as follows:

$$L_m = W + \left(y \times T \times \pi \times \frac{D_1}{S}\right)$$

$$L_e = L_m - W$$

where L_m = length of mean copper (half turn).
L_e = length of end loop (one end from cell extension to cell extension).
y = factor depending on number of poles as follows:

Poles	y
2	1.3
4	1.5
6 and more	1.7

W = width of core plus cell extensions.
T = actual throw of coil in slots.
D_1 = stator bore diameter plus depth of one slot.
S = total number of slots in core.

3-17. INSULATION SYMBOLS FOR RENEWAL PARTS COILS

A standard indexing system has been provided by NEMA (Standard RP4-10) for designating the class of insulating materials and other important features incorporated in the design of coils for rotating electric apparatus. This index consists of a grouping of insulation classification symbols contained in the American Standard for Rotating Electrical Machinery (C50) plus the letters N, X, V, and U. The first letter of the index is the ASA classification symbol for the conductor insulation, the second for the ground insulation, and the third for the outside binding tape. The

FIG. 3-21*a*. INSULATION SYMBOLS FOR RENEWAL PART A-C AND D-C FIELD COILS

Dipped treatment	Vacuum and pressure impregnation	Class of insulation*		
		Conductor	Ground	Binder
AAA	AAAV	A	A	A
AAB	AABV	A	A	B
ABB	ABBV	A	B	B
ABA	ABAV	A	B	A
ANN	ANNV	A	N	N
ANA	ANAV	A	N	A
BBB	BBBV	B	B	B
BAA	BAAV	B	A	A
BAB	BABV	B	A	B
BBA	BBAV	B	B	A
BNN	BNNV	B	N	N
HHH	HHHV	H	H	H
HNN	HNNV	H	N	N

* ASA Standard C50.

substitution of N indicates the absence of that particular insulation, and the letter U indicates untreated asbestos binding tape. The fourth letter, if present and if X, indicates that the coil is made to slot size. The letter V indicates vacuum and pressure impregnation and is used as either the fourth or fifth letter depending upon whether or not X is used. For example, index ABAX means class A conductor insulation, class B ground insulation, class A outside binding tape, and the X indicates that the coil is slot size and normally does not require a slot cell. Figure 3-21 gives

FIG. 3-21*b*. INSULATION SYMBOLS FOR D-C ARMATURE, A-C STATOR, AND SLIP-RING ROTOR COILS

Index				Class of insulation†		
Nonslot size*	Slot size	Vacuum and pressure impregnation				
		Nonslot size*	Slot size	Conductor	Ground	Binder
AAA	AAAX	AAAV	AAAXV	A	A	A
AAO	AAOX	AAOV	AAOXV	A	A	O
ABA	ABAX	ABAV	ABAXV	A	B	A
ABO	ABOX	ABOV	ABOXV	A	B	O
ABB	ABBX	ABBV	ABBXV	A	B	B
ANN	....	......	....	A	N	N
ANA	....	ANAV	....	A	N	A
ANO	....	ANOV	....	A	N	O
AOO	AOOX	....	....	A	O	O
BBB	BBBX	BBBV	BBBXV	B	B	B
BAA	BAAX	BAAV	BAAXV	B	A	A
BAO	BAOX	BAOV	BAOXV	B	A	O
BBA	BBAX	BBAV	BBAXV	B	B	A
BBU	BBUX	BBUV	BBUXV	B	B	U
BBO	BBOX	BBOV	BBOXV	B	B	O
BNN	....	....	....	B	N	N
BNB	....	BNBV	....	B	N	B
BNA	....	BNAV	....	B	N	A
BNO	....	BNOV	....	B	N	O
BNU	....	BNUV	....	B	N	U
HHH	HHHX	HHHV	HHHXV	H	H	H
HNN	....	......	....	H	N	N
OOO	OOOX	......	....	O	O	O
OAA	OAAX	......	....	O	A	A
OAO	OAOX	......	....	O	A	O
OBA	OBAX	......	....	O	B	A
OBO	OBOX	......	....	O	B	O
ONN	....	......	....	O	N	N
ONA	....	......	....	O	N	A
ONO	....	......	....	O	N	O

* Slot cells are not furnished with nonslot-size coils.
† ASA Standard C50.

a complete picture of conventional coil classifications.

3–18. COMMUTATOR CONSTRUCTION

The commutator is a rotating switch whose primary purpose is the conversion of ac into dc on a generator and dc into ac on a motor. A commutator such as shown in Fig. 3–22 consists essentially of a series of

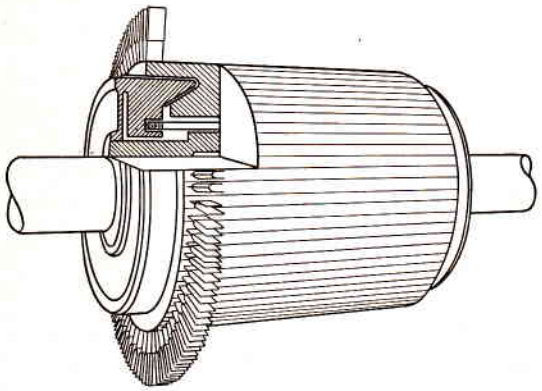


FIG. 3–22. Cross section of commutator showing V-ring insulation. (*Westinghouse Electric Corp.*)

copper segments assembled on a steel support with intervening insulation. This insulation has important mechanical functions in addition to its obvious purpose of insulating the parts of different potential. On very small commutators the parts may be molded together where the mechanical stresses are low. However, as commutators increase in size and peripheral speed, the mechanical characteristics of the insulation become more and more important. Different thermal expansion coefficients of the copper and iron produce differential expansion and relative motion when heated. This, together with the centrifugal forces produced by rotation, places great mechanical stresses on the insulation. In the larger commutators the insulation becomes a system of springs which absorbs and equalizes the forces of differential expansion as well as of centrifugal action. The bond in the insulation of a commutator must be thoroughly set when the commutator is ready to operate. Otherwise the parts will loosen and the bars may shift during operation. This would upset the equilibrium and produce a rough commutator. The insulating V ring or cone must be seasoned before the commutator is put into operation, as it has to withstand tremendous rotational forces on the V's. The insulating mica V ring should act as a system of springs but must not actually distort after the resin bond is set up. In all cases the segment insulation should be completely thermally set in the sheet form. It is usually sanded or machined to precise thicknesses before it is assembled with the copper segments. All commutators require some form of seasoning. On the smaller, simpler designs this may be only baking in an oven under controlled conditions. For the larger, more complicated commutators this may involve numerous oven bakes with re-pressing at intervals plus rotational seasoning, which may be repeated for several cycles.

Commutators generally employ composite mica sheet between their adjacent segments which has a thickness of from about 0.010 to 0.040 inch. This might be interpreted to mean that high-voltage stresses occur between adjacent commutator segments, but this is not the case. The voltage between bars is usually a very few volts and seldom above 20 volts. For peak bar-to-bar voltage on a commutator, 50 volts is about the absolute maximum. From this it is apparent that there is an entirely different reason for using mica as commutator segment insulation. Mica segment insulation is selected principally for its mechanical properties. Composite mica plate is effectually a system of springs, as mica has a uniform and reproducible degree of compression which is maintained throughout the

useful life of the commutator. In addition mica plate is highly resistant to temperature degradation, is not seriously affected by moisture, and is essentially nontracking under the conditions of arcing which it encounters on a commutator. **There are substitutes for mica plate which are at present under development and evaluation, but to date none of these appear to be better than mica plate.** Their advantages are primarily moderate cost and the use of nonstrategic materials. The mica substitutes for commutator segments now being used generally consist of asbestos and glass fibers bonded with special resins and carefully processed to obtain suitable mechanical characteristics. Any commutator segment insulation must be entirely cured to an infusible state before the completion of the commutator. It is generally preferable that this curing be done in the plate form. If any thermoplastic material remains in the segment insulation, there is a tendency for it to slip and ooze out under heat and pressure. This will result in loosening of the commutator and failure to maintain the necessary smoothness of the surface.

Commutators generally employ a V ring for holding the segments in a cylinder. Steel V's which provide the clamping action must be insulated from the copper commutator segments. This insulating V ring is made from flexible, molded mica sheet which is formed to the desired contour and then pressed and baked to its final size and shape. On very small commutators for fractional horsepower motors the mica V ring may be molded from a single disk of hot molding mica, but this requires very special tooling and production facilities. On large commutators the multiple sheets of molding mica must be carefully notched and the notches staggered in the molding process to assure a solid dielectric barrier at every point. Only in small molded commutators is some other material than mica used for clamping the commutator segments. As stated earlier the bar insulation has little significance as insulation, since bar-to-bar voltages are low. However, it is customary to test new commutators from bar to bar at a-c (rms) voltages of 200 to 500 volts. On the other hand, the mica V ring performs an important electrical insulating function as well as its mechanical duties. It must maintain a dielectric barrier between the commutator parts, which are at high potential, and the steel parts, which are at the potential of the frame, usually ground.

There are three general mechanical constructions of V-type commutators not including the molded type. These are (1) the ring-nut type, which has minimum flexibility; (2) the bolted type, which has some degree of flexibility; and (3) the spring-ring type, which has the maximum degree of flexibility. A completely different construction of commutator is the shrink-ring type, which has no V's. The segments are held by steel shrink rings applied to the outer cylindrical surface over mica insulation. Shrink-ring commutators are employed on very high speed machines such as direct-connected exciters on turbine generators operating at 3,600 rpm.

There are several philosophies of commutator manufacture and seasoning. One applies largely to the smaller commutators wherein the V rings are made by mass-production methods from hot-molding mica plate which is not cured until assembled in the commutator. A second philosophy employs mica V rings which are molded and cured under pressure until they are well into the B stage of the bonding resin, where, though somewhat thermoplastic, they are not so readily re-formed. This permits

some deformation of the V ring to adjust to the irregularities of the steel and copper parts during the assembly of the commutator but requires seasoning the commutator to complete the cure of the resin in the mica V ring. The third philosophy employs mica V rings that are completely thermoset, so that the resin is in the infusible stage before assembly of the commutator. This necessitates precise premachining of the steel and copper parts, as no adjustment of the mica cone or V ring is possible during seasoning.

Commutators operating at very high peripheral speeds do not employ V-ring construction. For these very high speeds "shrink-ring" commutators, such as shown in Fig. 3–23, are generally used. The segment insulation is similar to that employed on V-ring commutators, but the copper segments are held together by steel shrink rings applied outside the assembled segments. The shrink rings are insulated from the copper segments by flat composite mica strips which are wrapped around the assembled segments and segment insulation. The shrink rings are then heated and shrunk onto the assembly. The mica creepage extensions on both sides of the shrink rings are banded down by means of insulating cord which is usually treated with a quick-drying synthetic resin or shellac compound. Shrink-ring commutators require careful seasoning at temperatures above those at which they will operate in service.

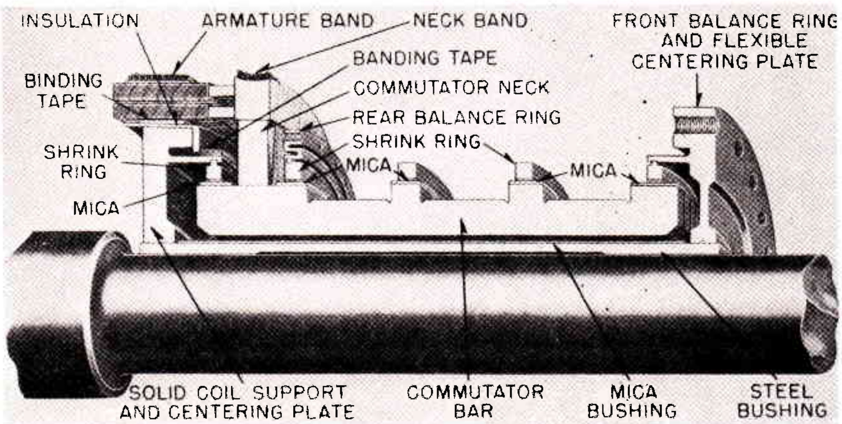


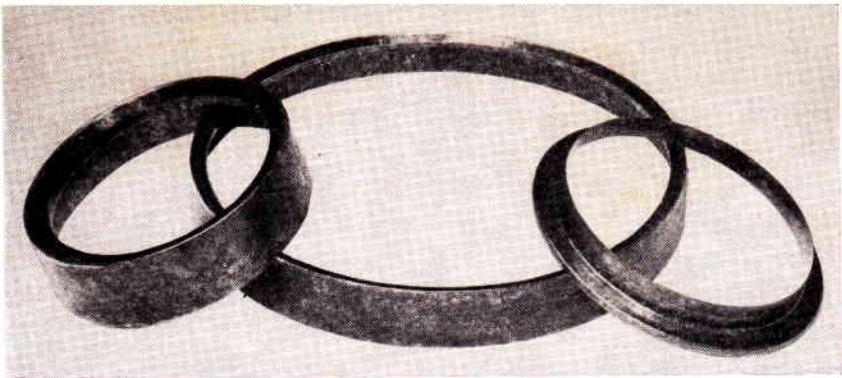
Fig. 3–23. Shrink-ring commutator. (*Westinghouse Electric Corp.*)

3–19. TYPES OF COMMUTATOR V RINGS

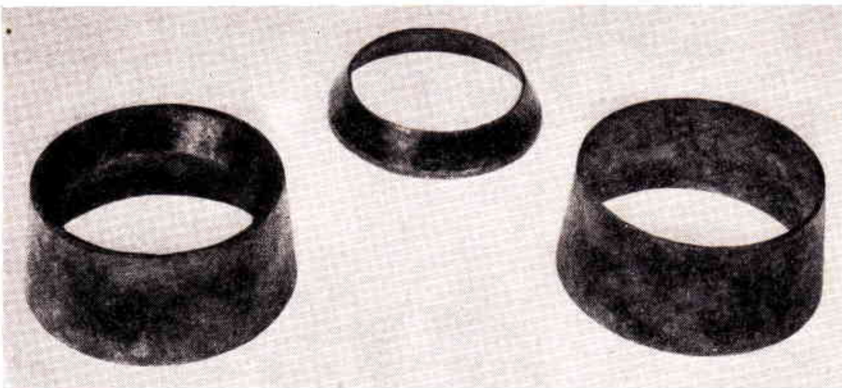
One-piece rings are preferred where the design and size permit and where the quantity to be manufactured justifies the mold expense. These rings consist of a single piece of molded mica which can be held to uniform shape of controlled denseness. One-piece rings are much easier to assemble in commutators on a production basis. They do require special molds which may have prohibitive cost for larger sizes.

Two-piece rings consist of an inside ring which is tapered and fitted into a band ring. This type of ring requires that additional space be machined from the copper segments to obtain creepage at the juncture of the two rings. The tools required for two-piece V rings are inexpensive in comparison with molds for other types. Two-piece rings are sometimes used on large custom-built commutators.

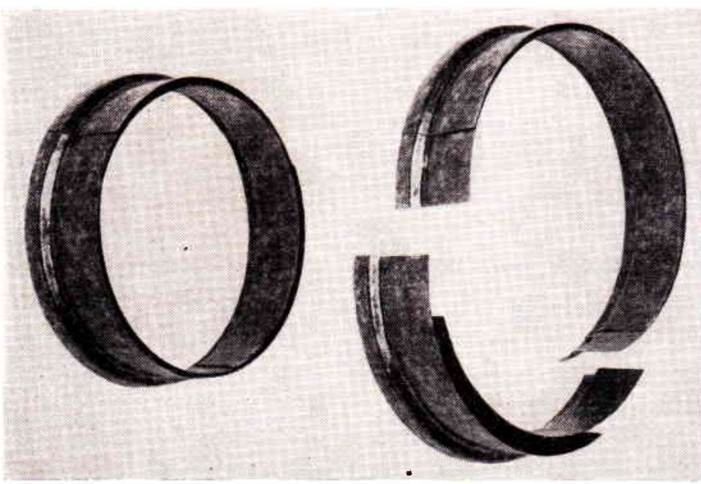
Sectional rings are made in segmental pieces. The joints are staggered and butt-



One piece



Two piece



Segmental

FIG. 3–24. Types of mica V rings. (*Mica Insulator Co.*)

lapped when assembled. They require somewhat greater mica thickness than the one-piece ring but produce the same effect as the one-piece ring. Such rings are used on large commutators where the expense of a one-piece mold is not justified or where the size of the commutator precludes the ring's being made in a single piece.

The various types of mica V rings are illustrated in Fig. 3–24.

3–20. COMMUTATOR STRING BANDS

The mica V-ring extensions in commutators generally do not have adequate mechanical strength to withstand the centrifugal force under operating conditions. These mica rings must be held down by the application of insulating bands such as shown in Fig. 3–25. Generally these bands

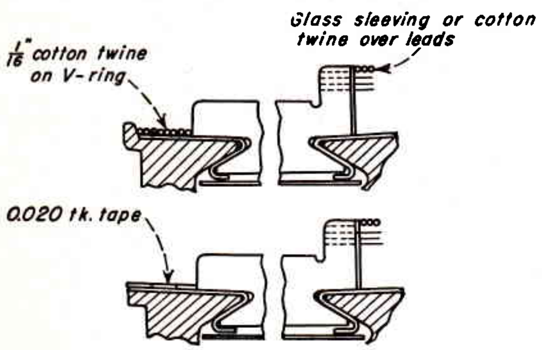


FIG. 3–25. Application of string bands and hoods to mica V rings on commutators.

can be applied when the winding is complete (or during repairs) after the complete winding has been dipped and baked. An excellent type of material for a string band is a cotton twine of rather fine texture. Sometimes tape (or cloth) is applied to the mica V-ring extension of slow-speed commutators. The twine or tape should be tightly applied under tension over a V-ring extension which has been freshly painted with varnish, shellac, or a red insulating enamel. Most alkyd resins and some of the phenolics are satisfactory for this purpose, as they have reasonably good arc resistance. Shellac also is a very good resin for this application. After the string band has been completely wound in place, the string should be carefully tied so as not to leave a lump or protruding knot. The surface should then be thoroughly covered with several coats of varnish, shellac, or red insulating compound. Each coat should be allowed to dry and should be sanded lightly before the application of a subsequent coat. A sufficient number of coats should be applied to form a glossy, smooth surface without serious imperfections. Such a surface will prevent the accumulation of carbon dust and other contaminants and resist tracking should the motor or generator flash over.

3–21. SLIP RINGS

Slip rings are employed on a-c motors and generators in order to bring electrical connections from the rotor to external circuits. For example, synchronous machines require excitation of the d-c rotating field. Another use is on wound rotor induction motors where the speed is controlled by external resistance which the control system inserts in series with the rotor winding.

Slip rings consist of simple ringlike contact members mounted on an insulating support. Several typical examples are shown in Fig. 3–26. Both iron and bronze materials are used for the collector rings, depending upon design qualifications. For small, low-speed work the insulation may be made of a molded compound. For somewhat higher speed and larger sizes the contact rings are mounted on laminated tubing. On higher speed applications, where the rotating parts are subjected to severe centrifugal forces and design becomes more complex, it is customary to employ a press fit between the shaft and the supporting steel bushing.

This necessitates the use of a mica insulating bushing under the contact rings. In this design it is frequently customary to heat the individual contact rings and shrink them

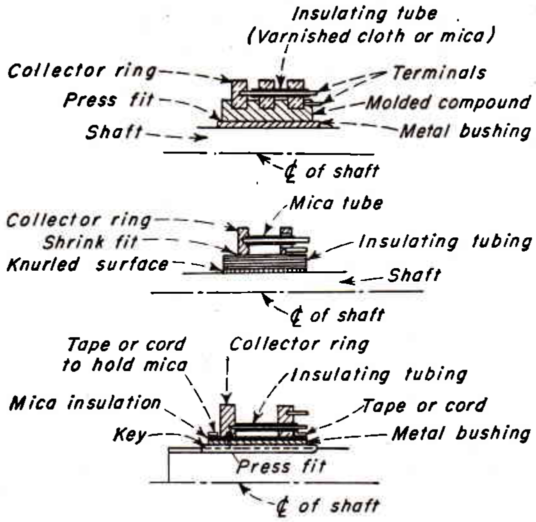


FIG. 3-26. Types of slip-ring construction.

onto the mica-insulated steel bushing. It is important that the rings be at the right temperature so as not to damage the resin bond in the mica insulation. Good practice dictates that the metal collector ring should not be above 400 C when it is placed in contact with the mica. It must be cooled quickly to prevent damage to the bond. High-speed collector rings, employing mica insulation, must have their insulating creepage surfaces banded with string (as commutator V rings) to prevent delamination of the mica flakes at high operating speeds. For this purpose cotton or glass twines are commonly employed. They should be filled with a good insulating air-drying compound to obtain a smooth finished surface which is arc resistant. Shellac and alkyd enamels containing iron oxide pigment are both satisfactory for this work.

3-22. BRUSH RIGGING

The simplest brush holders are mounted on studs which have insulating sleevings over them. On large machines there may be several individual brush holders mounted on a single arm. In that case the bar or arm must be supported and insulated from the frame. This is generally accomplished by the use of plates, washers, and bushings of laminated or molded insulation.

3-23. BRUSH HOLDERS

The brush box may be insulated from its mechanical support on the frame in a number of ways. Three forms of providing this insulation are shown in Fig. 3-27. In the simplest form a stud is insulated by laminate tubing and washers, and a porcelain ring provides surface creepage at the end of the stud. Frequently the stud insulation is covered by a thin brass sleeve to which the brush holder is clamped. A second form employs a through bolt with a simple laminate tubing. The rigging is clamped through to the insulating tubing, which provides solid insulation and creepage surfaces. A third form involves a special type bolt with the bolt insulated from the motor frame with a combination of insulating tubing and washers.

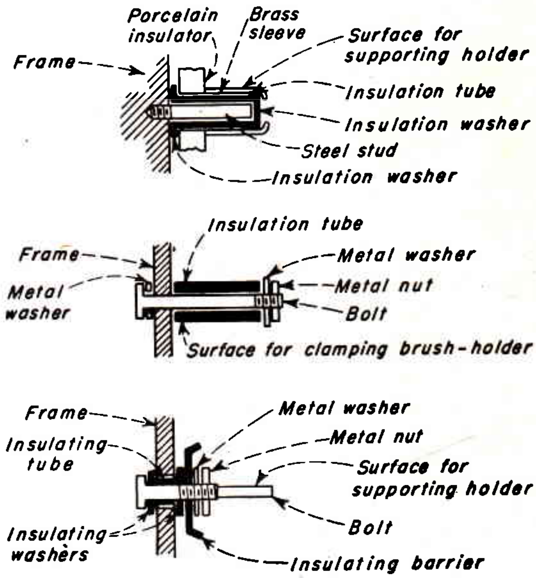


FIG. 3-27. Types of brush-holder insulation.

4. Apparatus Assembly and Winding Problems

Materials have been described and classified in Chap. 2, and their use on coils and parts of machines has been discussed in Chap. 3. This chapter will be concerned primarily with the assembly of coils into the complete apparatus with the supplementary materials required for completing the insulation of the machines. The necessity for high-quality materials and careful workmanship on coils and detail insulating parts has been emphasized previously. It is equally important that these coils and parts be carefully assembled into the complete machine in order to obtain high-quality windings. **Improper handling of coils during the winding operation can render useless all the development and design work, the selection of high-grade materials, and careful technique of fabrication of the coils.** Probably the major damage occurs to coils during winding, particularly if the coils are abused when they are forced into the slot or twisted when the "throw" is completed or put under excessive pressure during wedging and banding. There is no substitute for careful workmen with a clear understanding of winding problems and technique. Different kinds of insulation and coil designs require different winding techniques. A winder who is competent with one type of winding may fail in winding a different type of coil or insulation. The importance of winding technique cannot be overemphasized.

4-1. CLASSIFICATION OF MOTORS AND GENERATORS

There is no definite line of demarcation between large motors (and generators) and small ones. Examination of very large machines in comparison with the smaller ones discloses considerable differences in winding construction and insulating practices even at the same voltages. These practices are largely dictated by economic considerations which depend upon whether the particular size is mass-produced on a production line or "tailor-made" in small quantities. In general, motors up to about 100 horsepower are built on production lines and their designs are primarily aimed at manufacturing an economical product which can be quickly wound with a lower labor cost. Motors of 200 horsepower and above are generally in the tailor-made class, and their size and importance justify a higher labor content in the manufacturing costs of winding. Most generators are in this larger size and are in the same production class as very large motors. In the

range between 100- and 200-horsepower motors there will be an overlapping of these two classifications, depending upon manufacturing conditions and the quantity in which they are built. In the larger sizes coil construction is frequently determined by mechanical problems involved in bracing the windings for high-speed operation and against magnetic forces. In the lower horsepower class the voltages are usually lower (440 volts or below) and the magnetic and mechanical problems are not so critical.

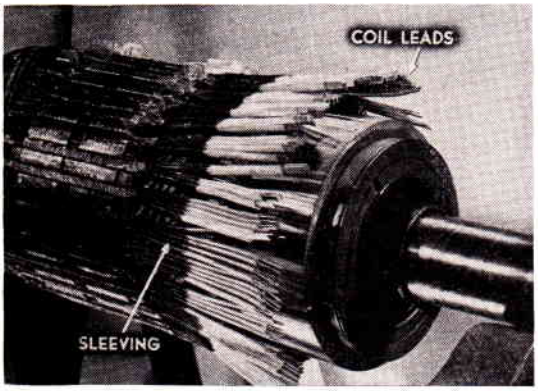
There is generally no significant difference between motors and generators as far as the machine construction or winding is concerned. Because of the nature of the requirements there are usually no very small generators except for very special applications. Therefore, it is not possible to classify windings according to whether they are used in motors or generators, as the classifications are largely based on physical size, rating, voltage, speed, and mechanical considerations.

4-2. D-C MACHINES

All d-c machines are somewhat similar in appearance and construction regardless of size. The armature is the rotating member and is made of laminated iron with slots into which armature coils are wound. The armatures carry commutators to which the armature winding is connected. Field windings are always in the stator and are nearly always on salient poles rather than embedded in slots. Figure 4-1 shows a typical d-c motor armature winding. Most d-c machines are operated at voltages well below 1,000 and have quite different insulation problems from a-c machines. **One peculiarity of all d-c machines is that they have large exposed creepage surfaces which are susceptible to contamination by moisture, oil, and dirt.**

4-3. INDUCTION MOTORS

The induction motor is one of the most common forms of electric motor. The armature winding is in the stator and is embedded in slots. It is essentially a constant-speed motor, although some varieties have wound rotors for speed control. Figure 4-2 illustrates the stator winding of a small induction motor. The simplest form of induction motor has a squirrel-cage type of winding on the rotor and needs no insulation, as the conductors are solidly connected to those in the next slot by end rings and need no insulation from the core.



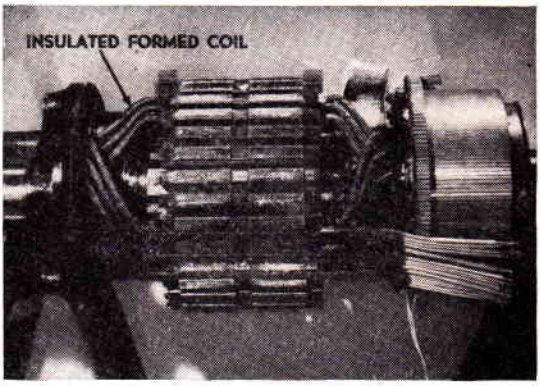


FIG. 4-1. Typical d-c machine winding. (*General Electric Co.*)

Wound-rotor induction motors have rotor windings which are often similar to the armature coils in d-c armatures except that they are connected differently and their leads are brought out from the rotor through slip rings rather than a commutator. The field is large in diameter and carries many poles, and the stationary armature is usually relatively short in axial length. Armature coils are often the preformed and preinsulated variety and may be either pulled or formed. Field coils are frequently wound

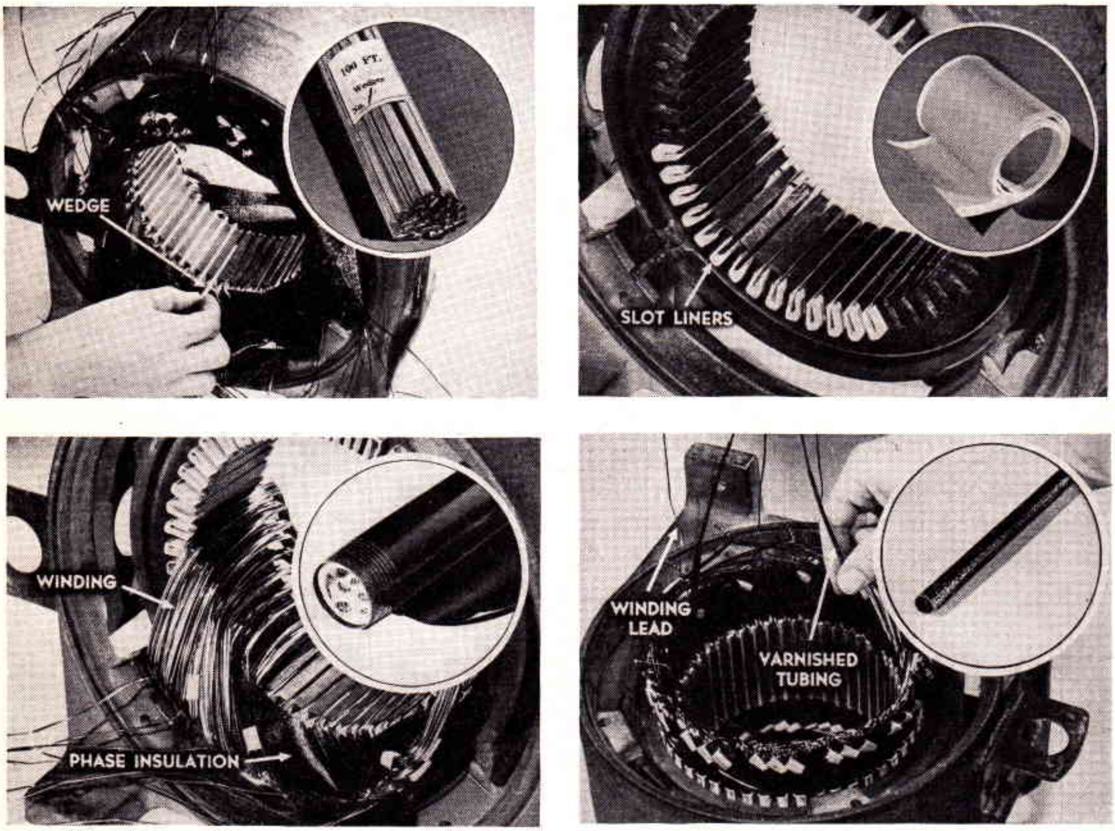


FIG. 4–2. Typical induction-motor winding. (*General Electric Co.*)

slot construction may be either open or partially closed, and coils either random wound or preformed and insulated. The insulation requirements for the rotor coils follow d-c armature coils of the same voltage and speed classification.

4–4. SALIENT-POLE SYNCHRONOUS MACHINES

Many large motors and generators which are built for relatively low-speed operation fall into this classification. The revolving on the poles and insulated therefrom by cells which are placed on the poles before the coils are wound. This is particularly true of field coils wound from small or medium-size wire. Other field coils, particularly those wound of edge-wound strap copper, may be preformed and insulated with cells before being placed over the field poles. Figure 4–3 shows a salient-pole synchronous motor.

This class of machine may be either a motor or a generator. For example, most

engine-driven generators are of the salient-pole construction. Large water-wheel generators are also of this general type, but employ special mechanical construction for physical reasons. Most large water-wheel generators have vertical shafts and are arranged with the hydraulic turbine below. This makes no difference in the insulation problems but does affect mechanical design of the machine.

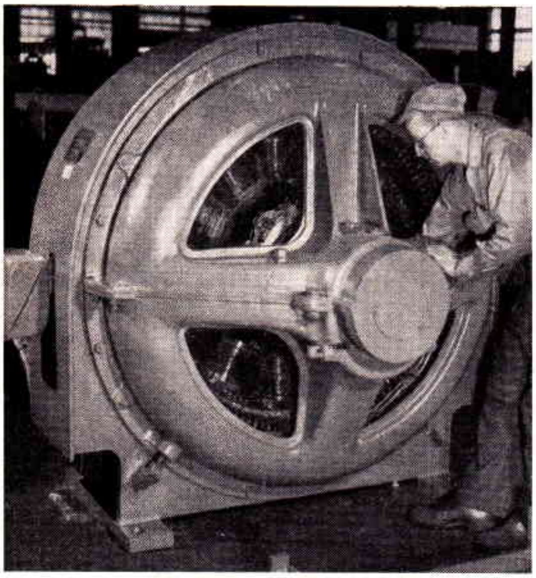


FIG. 4-3. Salient-pole synchronous motor. (*Allis-Chalmers Mfg. Co.*)

4-5. TURBINE GENERATORS

The turbine generator is a very specialized type of electric generator designed primarily for high-speed operation so that it may be connected directly or through gears to a steam turbine. Turbine generators for 60-cycle operation are usually six-pole operating at 1,200 rpm, four-pole operating at 1,800 rpm, or two-pole operating at 3,600 rpm. For example, ships' service generators are frequently connected to their turbines through gears. Turbine generators employ a very special type of rotating field because of the high operating speeds. Coils must have special mechanical supports, since for the very large sizes they have great lengths of core. The mechanical part of the rotor is usually a steel forging with the slots milled into it. The field windings are generally flat-wound heavy copper straps employing mica tape flatwise between turns. The ground insulation for the field coil is generally a molded mica cell. A typical rotor assembly is shown in Fig. 4-4. Very specialized processes are necessary for winding and cementing the turns of the field coil in place. A great deal of care goes into the physical clamping and supporting of the turns of these coils to ensure mechanical stability under the high centrifugal stresses during operation. Actual insulation requirements are simple, as these fields usually operate at 250 volts dc and nearly always less than 500 volts dc. Positive separation is used between turns. Reasonable creepage distances to ground provide adequate insula-

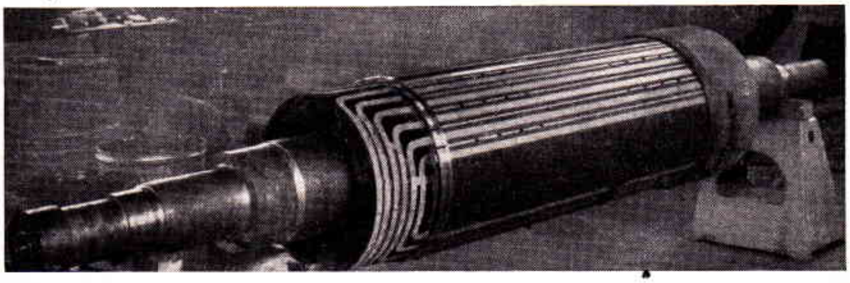


FIG. 4-4. Turbine-generator rotor assembly. (*Electric Machinery Mfg. Co.*)

tion beyond the ends of the mica slot cells.

Armature coil windings for turbine generators are usually similar to those for salient-pole motors and generators except that frequently the coils are made in halves for ease of winding, especially on one-turn coils. This complicates the connections, as every turn and strand must be connected at both ends of the core. However, it does make for ease of winding and minimizes the probability of physical damage to the insulation during winding. Furthermore, it facilitates the repair or replacement of a single half coil. Figure 4–5 shows a typical turbine-generator stator winding with its characteristic long core with small bore and involute end windings. Modern high-voltage turbine-generator armature coils employ continuous mica-tape ground insulation almost exclusively. Several important manufacturers now supply asphalt-bonded tape applied continuously from end to end of the coils, generally with multiple impregnation with an asphaltum compound. Earlier designs employed the so-called "mica folium" type of insulation which was wrapped and ironed onto the straight part as a tube. This necessitated a joint between the ground insulation and the end-turn insulation. End-turn insulations of both mica tape and treated-cloth tape have been used. Mica folium insulation on the straight parts and taped end windings are still manufactured in several foreign countries.

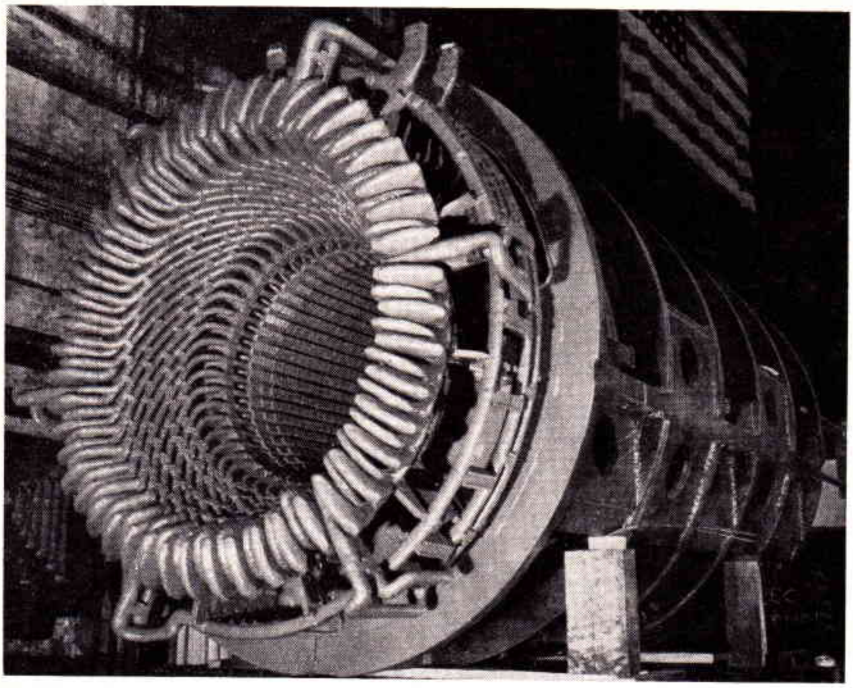


Fig. 4–5. Turbine-generator stator winding. (*Westinghouse Electric Corp.*)

Turbine generators are usually high-voltage machines and may require corona-suppression treatments. The major manufacturers of such equipment provide semiconducting surface treatments on the slot part of coils and sometimes in the end

windings for the suppression of corona. This treatment is usually applied during the manufacture of the coil.

4-6. CREEPAGE AND STRIKING DISTANCE

Expediency is an important factor in the design of electrical insulation. For example, there is a vast difference in the space that can be made available for insulation in a large motor and a fractional horsepower motor, both of which may operate at the same voltage. This difference will be particularly evident in the creepage and striking distances that are allowed between parts of opposite potential. In addition the conditions under which a motor may operate will also determine the creepage and striking distances that should be allowed. A machine which is known to be operated in a clean, dry atmosphere may have a far smaller factor of safety than one which the designer expects to operate under adverse conditions of humidity or chemical contamination or where excessive conducting dirt particles may be present.

The importance of the machine's duties may also determine the factor of safety allowed. For example, a ship propulsion motor is a great deal more important to the lives and safety of the crew than a fan motor, especially where the latter is one of several. It will therefore be found that the factors of safety allowed for insulation creepage distances will vary depending upon the importance of the service rendered as well as the physical size, voltage, and economic factors. The evaluation of all these factors requires the exercise of considerable judgment, which must be based on a suitable background. No textbook or design standard can hope to reduce this to a formula. It has frequently been said that the designing of insulation is an art rather than an exact science. The tabulations in Fig. 4-6 list several kinds of apparatus by voltage class and service and indicate the approximate creepage and striking distances that are commonly used by design engineers.

All dimensions are in inches. Values are for conventional open construction except submarine propulsion motors, for which values given apply to enclosed construction with recirculated ventilation.

4-7. WINDING PROCEDURES

Random Windings. Slot cells are first placed into the core; next the prewound turns are inserted into the slot, usually as a loose bundle. On partially closed slots care must be taken not to scuff the wire insulation on the edge of the slot opening, as the individual wires are threaded into

FIG. 4-6a. APPROXIMATE STRIKING DISTANCES THROUGH AIR USED FOR DIFFERENT VOLTAGE CLASSES OF D-C MACHINERY FOR VARIOUS KINDS OF APPARATUS

Voltage class	Fractional hp motor	Small industrial motor	Large industrial motor	Railway motor	Submarine propulsion motor
Below 150	1/16	...	...	1/16	
150-300	1/8	1/4	3/8	1/8	
300-500	1/4	1/4	3/8	1/4	3/8
500-750	...	3/8	1/2	3/8	3/8
750-1,000	...	...	1/2	1/2	1/2

Fig. 4-6*b*. Approximate Creepage Distances over Insulation Surfaces Used for Different Voltage Classes of D-c Machinery for Various Kinds of Apparatus

Voltage class	Fractional hp motor	Small industrial motor	Large industrial motor	Railway motor	Submarine propulsion motor
			Cell extension		
Below 150	¼	. . .	. . .	3/16	
150–300	5/16	½	. . .	⅜	
300–500	⅜	⅝	¾	9/16	¾
500–750	. . .	¾	⅞	⅝	¾
750–1,000	. . .	. . .	1⅛	¾	⅞
			Commutator V-ring extension		
Below 150	¼				
150–300	5/16	½	. . .	⅝	
300–500	⅜	¾	1⅛	¾	1
500–750	. . .	¾	1½	1¼	1¼
750–1,000	. . .	. . .	2	1½	1½

the slot. After the wires are placed completely in the slot, they should be bedded down in the slot carefully so as to avoid damage to the turn insulation, cutting the cells, or tearing the edge of the cell which provides creepage. After the bottom coil sides have been wound, the separators should be placed in the slots and the top coil sides of the coil wound in a manner similar to the bottom coil sides. The insulation between phase groups and between coils in the end windings should then be placed in its proper position. Next cell edges are folded over, and the wedges or slot sticks are driven into place. The end windings are then formed and either taped or tied with cord, twine, or sleeving.

Preformed Coils. Preformed and preinsulated coils are frequently made "slot-fit" in classes B and H. However, class A coils are often used with fish-paper winding cells. The coils should be carefully inserted in the slot and are usually a snug fit. The first coils placed in the slot should not be driven completely to the bottom, since it will be necessary to raise the top coil sides as the "throw" is completed. The bottom coil sides of the first few coils should therefore be placed lightly in the slot. Coils should be centered in the slots as they are wound and should be driven to the bottom of the slots with fibre drifts (or some other insulating drifts). Metal drifts should not be used in contact with the coils, as they will cut the insulation surfaces and may bruise the insulation internally. As the winding progresses, the slack in the ends should be taken up by forming the coils slightly against their spacers or against the adjacent coils. If this is not done, it may be difficult to get the last few coils into the remaining space. This will result in crowding which may damage those coils. Frequently there are winding pads and in-

sulating strips which are part of the winding material. Such pieces are more commonly used on d-c armatures between top and bottom of coils in the ends. Such pads often consist of treated asbestos or fiber-glass cloth for class B or cotton cloth for class A on either side of fish paper and mica in several thicknesses. When the winding has progressed to the point where the "throw coils" must be raised, this should be done with great care, as it is a very critical operation. The coils that have already been wound in the slots should be raised for more than a throw, usually one and one-half to two throws back into the winding. When all the bottoms of the coils are in their slots, the throw coils should be tightened a little at a time until all are down in their slots. Then the final top coils can be driven in place.

Stator coils are then tightened with side strips and top filler strips where necessary, and the wedges are next installed. Armature coils in rotors require different processing, as they must be temporarily banded before being wedged and subsequently the final bands are applied to the end windings. In some cases core bands are also applied.

4–8. CROSS CONNECTIONS FOR PARALLEL–WOUND D–C ARMATURES

Large d-c armatures employing parallel circuit windings generally have cross connections between commutator bars of the same polarity and potential. These cross connections have as their purpose the equalization of the current in parallel brushes. Cross connections are usually copper strap of considerably smaller cross section than the armature coils and have a shape somewhat similar to the ends of the armature coil. They usually have insulation applied to them individually at least equal to the turn insulation of the armature coils. They are then insulated from ground as a group and must be insulated between layers with a heavy insulating pad when they are placed in the armature. On many designs of armatures these cross connections are placed at the bottom of the slots in the commutator necks or risers and frequently below the armature coils where they connect into the risers. On other types the cross connections are located at the rear of the armature and connect between points of coil ends. On a few types of motors the cross connections may be in a group that is assembled on the front commutator V-ring extension, where access may be obtained to them without disturbing the armature coils. Figure 4–7 illustrates this type of cross connection on an armature.

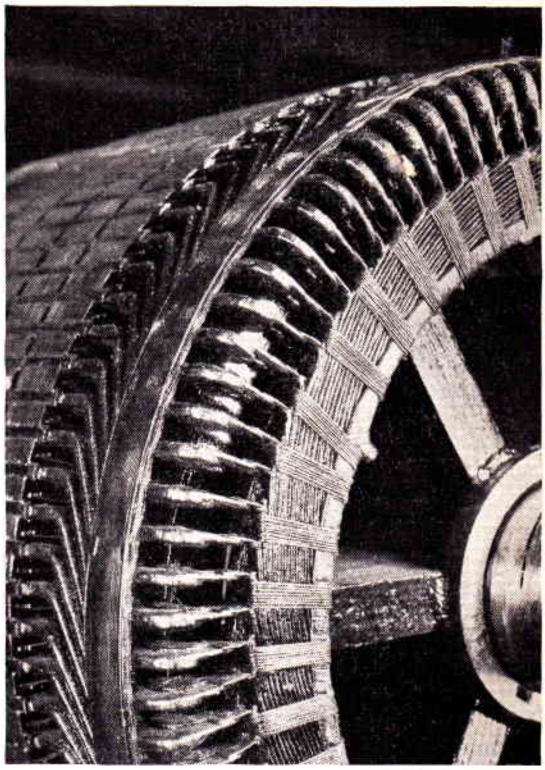
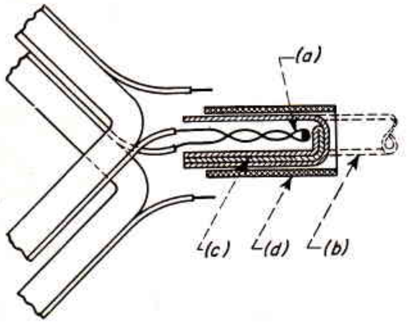


FIG. 4–7. Cross connections assembled on d-c armature. (*Westinghouse Electric Corp.*)

4-9. CONNECTIONS BETWEEN STATOR COILS

Connections between large wire-wound coils are important, as they involve both insulation and methods of connection. In "gang" random-wound coils the stub connections are eliminated. If groups of coils are wound continuously, the conductor progresses from coil to coil without joints. On



(a) Twisted and fused joint
(b) Inside tubing before being folded
(c) Inside tubing after being folded over the joint
(d) Outside tubing

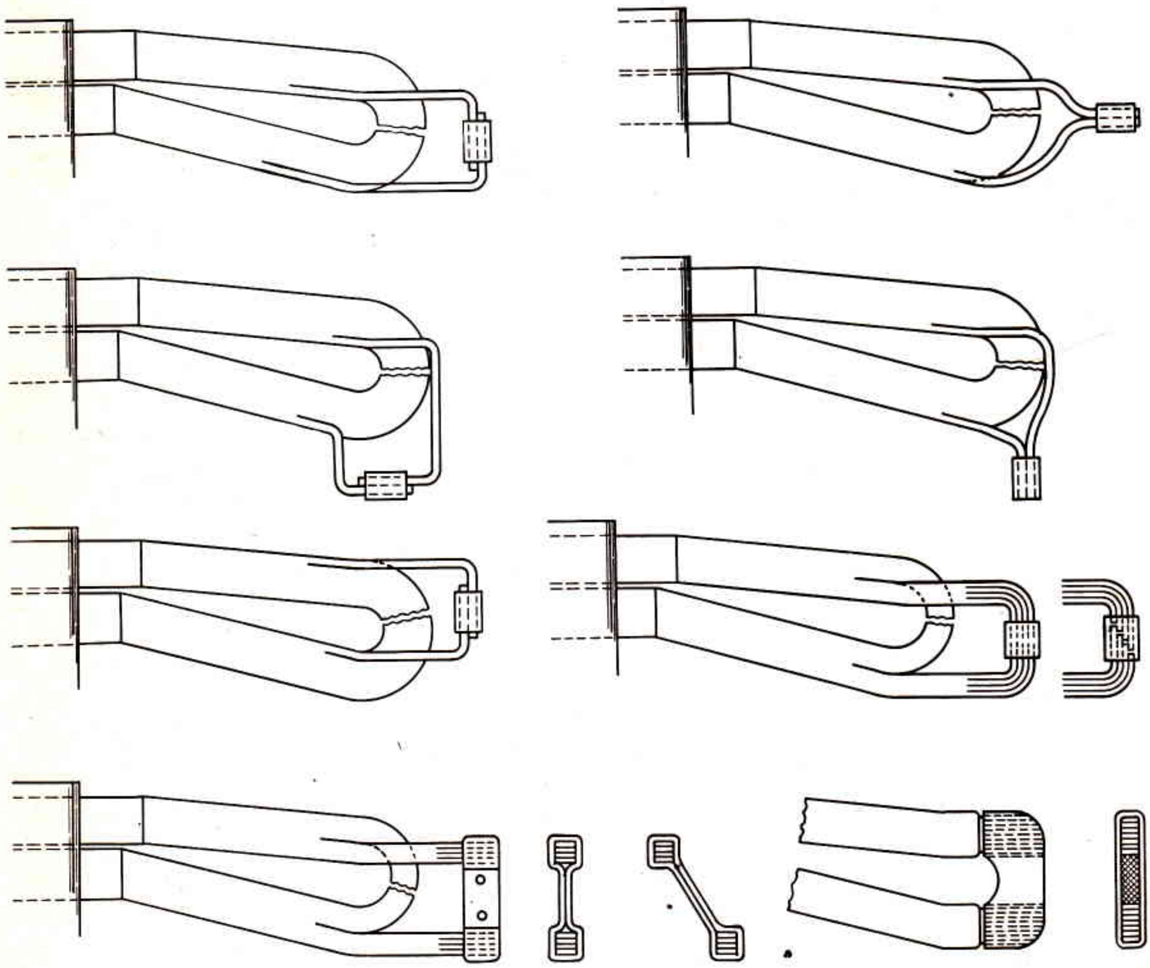


FIG. 4-8. Several methods of connecting stator coils. (*National Electric Coil Co.*)

larger random-wound coils where the single coils are handled separately, connection between coils can be made in two different ways. Coil ends are twisted together and fused by a gas flame. They may be skinned, tinned, twisted together, and then soldered. Copper sleeve connectors are sometimes used. The insulation of this type of connection is usually accomplished by the addition of a varnished tubing or by the application of varnished cloth tape and cotton tape for class A insulation or mica and fiber-glass tape for classes B and H insulation.

Usually motors employing random types of winding are for operation below 600 volts and are rated at not more than 50 horsepower.

Motors employing preformed and pre-insulated coils may have the windings connected in many different ways, but these can be divided into two general classes: (1) those which have conductors of relatively small cross section and (2) those having large cross-sectional conductors with a number of large strands in parallel. For all these types it is common practice to employ clips which slip over the stub ends of the coils. These clips serve a mechanical purpose of holding the wires as well as the electrical purpose of carrying part of the current. The insulation of all types of joints depends upon the operating voltage. The more common practice is to apply multiple layers of insulating tape. For class A insulation bias-cut varnished cloth tape is used, and for class B insulation mica tape is generally used. The basic ground insulation is then covered with a layer of surface binder tape, cotton for class A and fiber glass for classes B and H. In some cases special molded mica caps are provided to furnish the basic insulation and are held in place by conventional finishing tapes.

The coils for some large motors or generators may employ transposed strands within the turns to reduce eddy currents. Where these transpositions are carried from coil to coil, the joints between coils are made in the same manner as though the conductor groups were separate turns. Usually the transpositions are not taped separately but are merely spaced with some form of sheet insulation and the remaining space filled with a good insulating cement. The ground and binder insulation is then applied over the whole joint for a coil or turn.

Several methods of making connections are illustrated in Fig. 4–8.

4–10. WIRING AROUND FRAME

On d-c motors and generators there is frequently a considerable amount of wiring around the frame to connect between the field coils. There may be several such

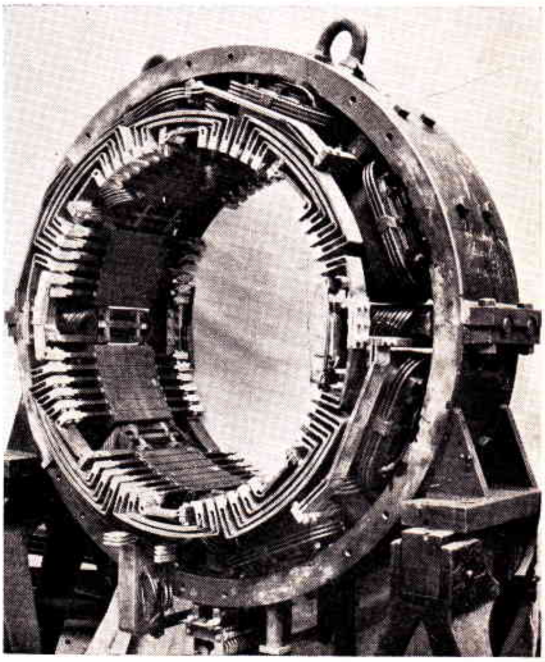


Fig. 4–9. Wiring around frame of a d-c motor. (*Westinghouse Electric Corp.*)

circuits, as the stator may include shunt field coils, series field coils, commutating field coils, and others all in a single frame. Where heavy strap connections are used and sufficient space is available to provide ample striking distance through air between circuits, there may be no serious insulation problem. Here some fabric tape may be applied for appearance purposes. On cramped designs and where the connections between coils lie against the frame, it is necessary to use adequately insulated connectors or cable. If insulated connectors are used which are against the frame or parts of other circuits, then full insulation for the circuit voltage must be provided. Frequently it is necessary to support the wiring around the frame mechanically on some parts of the frame. In that case adequate support members should be provided, and the connectors should be solidly lashed down with insulating cord or tape. A typical example of wiring around a frame is shown in Fig. 4–9.

4–11. SUPPORT FOR STATIONARY ARMATURE COILS

Many large a-c motors have operating cycles which involve sudden and appreciable changes in load. Full-voltage starting of high-speed a-c motors may take five to six or more times full-load current depending on the starting torque required. These current changes in stator coils are accompanied by electromagnetic forces which tend to distort the coil ends. It is therefore necessary to support coil ends so that they are not damaged by the magnetic forces. This is accomplished by adequate support and bracing of the coils to withstand these severe operating conditions. A good design of motor not only will provide adequate physical support for the coils when the insulation is new but will take into consideration the reduction in physical strength of insulation and lashing due to thermal aging, so that the coils will withstand the forces occurring throughout their life.

The slot portion of the coils should be held securely in place with nonshrinking wedges and slot filler pieces. These require no additional physical support on stators. The magnetic forces of high currents tend to bend the end turns outside the slots, to push them apart within each phase group, and to produce oscillating forces between phase groups. To support the coil ends it is customary to use coil support rings and to provide blocks between the ends of adjacent coils. Coils are lashed both to the support rings and to adjacent coils in the ends around the support blocks.

The extent of the bracing will depend upon:

1. The extension and span of the diamonds.
2. The rigidity of the coil and the amount of insulation.
3. Whether or not full-voltage starting is required and the duration of high current (with high inertia loads).
4. The severity and frequency of load changes and starting.

Short, stubby coil ends such as employed on slow-speed synchronous motors may be amply stiff so that they need no bracing. On higher speed motors the coil ends have a greater span and longer extension, which may necessitate lashing them to a support ring even though the duty may not be so severe. High-voltage coils generally contain more turns of smaller wire size than similar low-voltage coils. Therefore, the high-voltage coils are inherently not so stiff and generally require more bracing.

The methods of coil end bracing are:

1. One floating support ring to which each coil is lashed.

2. Rings supported by a mechanical attachment to the frame.

3. Multiple rings and spacing blocks between coils. The blocks are tied progressively from coil to coil, producing a rigid arch-bound assembly.

The coil support rings should be completely insulated for full voltage. The rings farthest from the core may be steel, but rings nearer the core should be nonmagnetic material in order to reduce leakage flux and resulting circulating eddy currents.

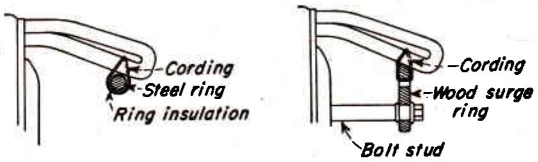


FIG. 4-10. Support of diamond-type coils with one support ring. (*National Electric Coil Co.*)

The particular method of tying or bracing is dependent upon the physical shape of the coils or windings and upon the design of the surge rings and the supporting brackets. Figure 4-10 shows a scheme used for half-turn diamond-type coils having only one support ring. The bottom half coils are lashed to the ring, and each coil is tied in to braces rigidly and fastened to adjacent coils by lashing. As the tying progresses from coil to coil, the end windings become a network of ties which bind the entire end winding. When properly done, the end windings form an arch-bound ring. The separator blocks are usually made of fibre or a laminated material. The top half coils are blocked and tied to adjacent coils in the same manner but are usually not lashed to a support ring. Figure 4-11 shows two common methods of beginning and ending a tie. Figure 4-12 shows the method commonly used for supporting the end windings of induction motors. Each coil is tied to the ring with multiple turns of tying cord. In some cases spacing blocks are taped on the coil diamonds during manufacture.

The cords employed for tying end windings may be cotton, hemp, flax, asbestos, or fiber glass. Whatever type of cord is used, it is advisable to pretreat the cord before use. Many varieties of cord, especially fiber-glass cord, are pretreated by the manufacturers. Pretreatment improves the abrasion resistance, protects the fibers from moisture, and usually results in better strength and heat resistance.

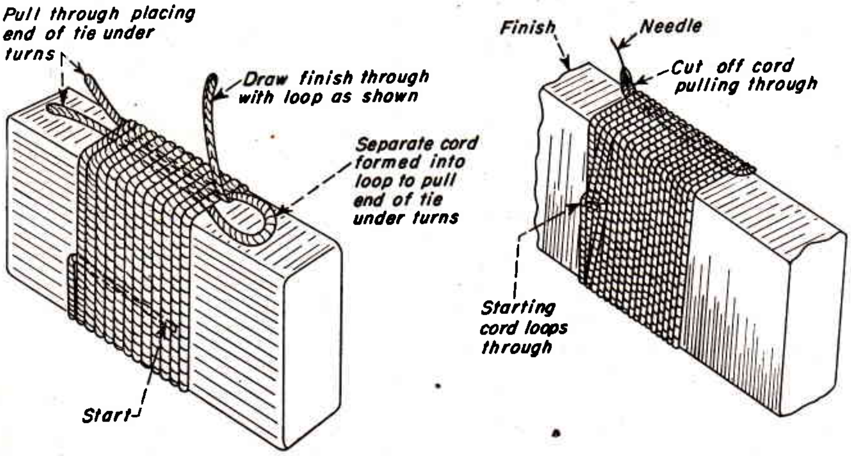


FIG. 4-11. Methods of making ties. (*National Electric Coil Co.*)

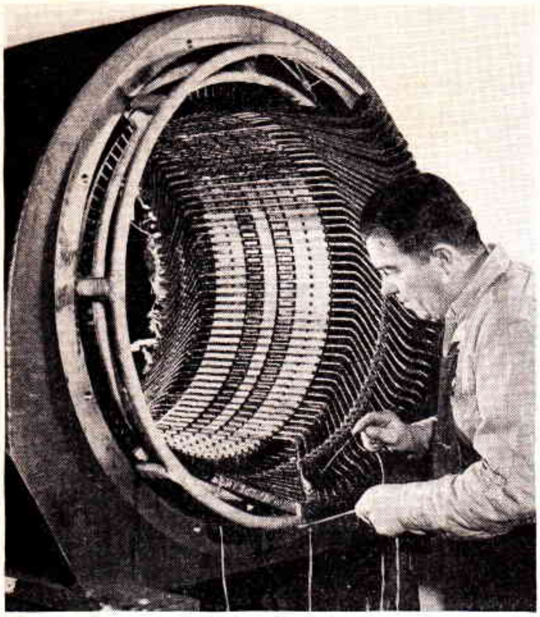


Fig. 4-12. Method for supporting induction-motor end winding. (*Electric Machinery Mfg. Co.*)

4-12. SUPPORTING D-C ARMATURE COILS

Armature coil ends must be supported so as to overcome the effects of centrifugal force. This is usually accomplished by banding the coil ends down against coil support rings, both front and rear. The nature of these support rings may vary widely, but all require some form of electrical insulation. Mica insulation for support rings is quite general and is frequently applied as sections of molding mica plate with staggered joints. On class A windings Fuller board or fibre channels are used. On some designs molded mica rings are used. These rings may be either continuous or segmental with staggered and lapped joints. The whole insulating structure can then be bound to the support ring with a binder tape of cotton, asbestos, or fiber glass.

After the armature coils have been wound into the slots, it is generally customary to hold them in place in the slots by means of wedges made of fibre or some form of laminate. The wedges must have sufficient mechanical strength to restrain the coils within the slot against centrifugal force during rotation and are designed for full-speed operation with a considerable factor

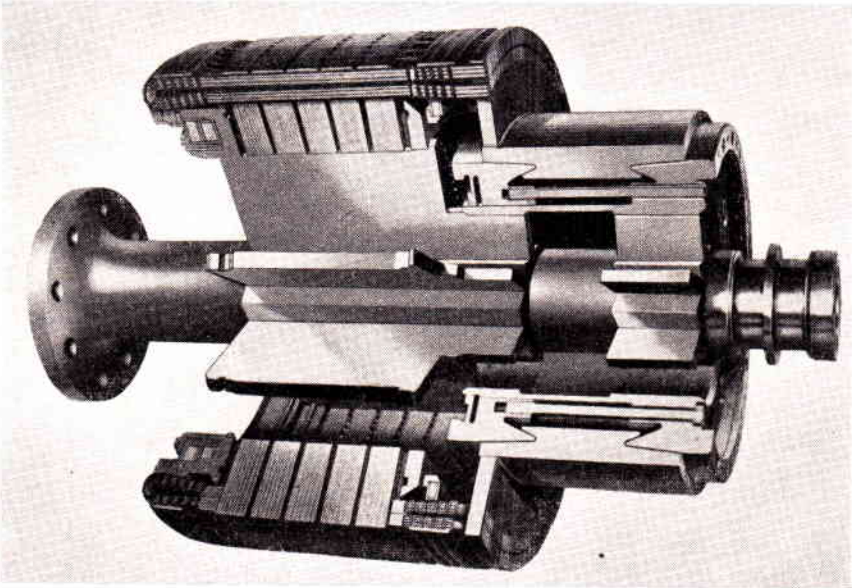


Fig. 4-13. Cross-section view of d-c armature showing coil supports, bands with insulation, and wedges. (*Westinghouse Electric Corp.*)

of safety. The end windings or diamonds of the coils present entirely different problems, and it is necessary to apply bands of steel wire to restrain these parts of the winding. Very careful and accurate calculations are necessary to determine the loads which the bands must withstand at the maximum speed of operation, and the selection of the band size and application conditions is a mechanical engineering problem. After application the bands must then be carefully anchored and soldered so as to maintain each band in its proper position. Obviously the bands must be insulated from the coil end windings, as the full machine voltage may be impressed from each coil to the band and to a coil of opposite potential elsewhere under the band. It is customary to insulate bands by means of multiple layers of mica or fish paper and mica or varnish-treated cloth supplemented by cotton, asbestos, or fiber-glass fabrics. Figure 4–13 shows coil supports, bands with insulation, and wedges.

4–13. SUPPORTING ROTATING FIELD COILS

All rotor coils must be secured against centrifugal forces, and special consideration must be given d-c fields on synchronous machines. Wire-wound d-c field coils are usually solidly bound or bonded together by the use of a thermosetting compound applied when the coil is wound. For relatively low operating speeds this may be adequate to overcome the centrifugal forces, but at high speeds additional bracing may be necessary along the face of the coil. A wedge-type bracing block of some insulating material is frequently bolted to the rotor spider as shown in Fig. 4–14.

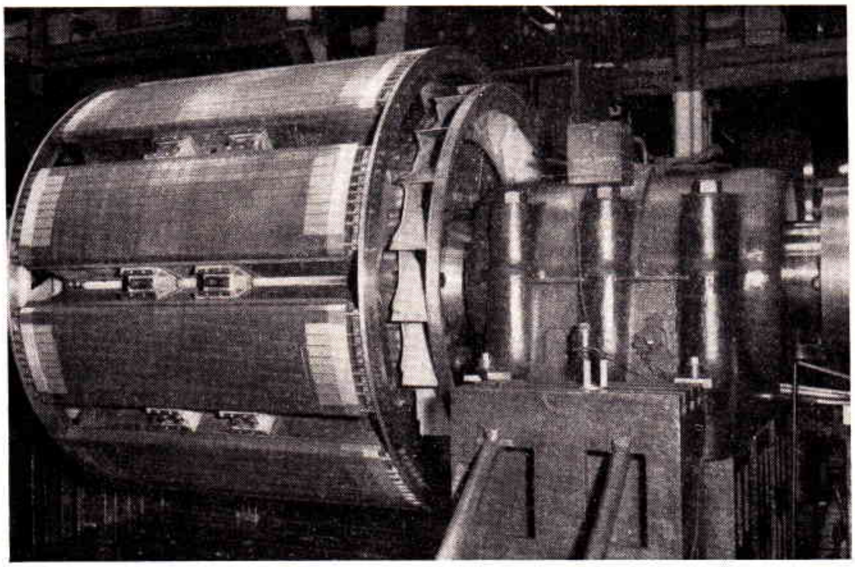


Fig. 4–14. Method of blocking rotating field coils. (*Westinghouse Electric Corp.*)

4–14. APPLICATION OF WEDGES AND SLOT FILLERS

1. Flat wedges and slot filling strips for all class A insulated equipment should be laminated glass-melamine material, type GMG. Maple or fibre flat wedges should not be used owing to inherent shrinkage.

Formed wedges of fibre may be used; however, development of an improved material is under way and it is expected to make available in the supply system a nonshrinking, nonswelling formed wedge in the near future.

2. Flat wedges and slot filling strips for all class B insulated equipment should be laminated glass-melamine material, type GMG. Mica filling strips of composite mica, glass, and organic varnish may be used.

3. Flat wedges and slot filling strips for all class H insulated equipment should be laminated glass-silicone material, type GSG. Mica filling strips of composite mica, glass, and silicone varnish may be used.

4. Filling strips of the proper thickness or thicknesses should be used to ensure enough pressure to hold the coils securely in place.

5. All wedging should be done with the apparatus at room temperature.

6. Wedges should be located in the core and should usually extend slightly beyond the core.

7. Care should be taken to avoid mechanical damage to insulation, especially when wedge drivers and spoons are used.

8. Care should be taken to avoid mechanical damage to wedges. Wedges which are cracked or broken must be removed and replaced.

9. A coat of CB varnish should be applied to the wedge grooves, and a coat of the same varnish brushed on the wedges after they have been driven into place.

4-15. USE OF PUTTIES AND CEMENTS

It is always undesirable to leave dead-air space within solid insulation or around connectors. It is therefore customary to fill such spaces with putties and cements before the outer insulation is applied. These filling materials should be fairly good insulators, but more important, they should have good filling properties with low shrinkage and high thermal conductivity so they do not produce overheating of adjacent conductors by impairing heat dissipation. On many d-c armatures, where dirt may contaminate creepage surfaces, it is desirable to block some of the air passages near the end of creepage surfaces so as to prevent the contamination of these surfaces with conducting materials. Putties and cements are quite commonly used for this purpose. Here it is particularly important that the materials be structurally strong to withstand centrifugal forces as well as provide good adherence to adjacent parts.

There is a wide variety of cements and putties which can be used, and these are available in many forms. In general the stiffer materials will have less shrinkage, although thinner materials are easier to apply. Some putties which can be applied with a gun are available in relatively low viscosity.

4-16. CORONA SUPPRESSION IN HIGH-VOLTAGE WINDINGS

Corona was defined and discussed in Sec. 1-23 as a phenomenon which occurs when gas is stressed electrically beyond the critical value. Corona is seldom observed in machines operating at less than 6,000 volts. Corona occurs in high-voltage windings in two locations:

1. Slot corona occurs within the slots when the gas in the tiny voids existing between the solid insulation and the punchings ionizes. This is overcome on modern high-voltage machines by the application of a semiconducting surface to the solid insulation. This semiconducting sheath contains the voltage stress within the solid insulation, collecting the capacitive current from along the coil side and discharging it harmlessly into the core.

2. End-winding corona occurs where the coils leave the slots and between adjacent coils in the ends. There is a concentration of the voltage stress at the edge of the iron, and corona may form on high-voltage windings along the surface of the insulation beyond the core or at the end of the semiconducting treatment on the slot part of the coils. It may also form between coils in the end windings, particularly between coils of different phases where the highest voltage stresses exist. In order to grade the voltage along the coil surfaces, a much higher resistivity surface treatment is applied to the part of the coils just beyond the core. This overlaps the low resistivity treatment for suppressing slot corona and satisfactorily distributes the voltage gradient along the coil surfaces into the end windings. Corona between phases in the end windings is usually avoided by sufficient spacing between the phase groups to prevent ionization of the gas.

Slot corona is not a serious hazard on machines having windings that employ mica ground insulation, since many machines have operated successfully for well over 20 years with considerable quantities of slot corona as observed visually and by odor. It has been noted that the corona damage is usually limited to surface oxidation. It also may result in accelerated aging of varnish films and other exposed organic materials. The use of fiber-glass binder tapes and tying cords was a major step forward in improving the resistance of high-voltage windings to corona attack. Surface treatments of iron oxide enamel are frequently applied over the basic coil impregnation, as the iron oxide enamel is resistant to corona attack. Evidence of corona attack on windings is usually in the form of a gray dust at points of highest potential, although sometimes it may appear as dark, discolored spots on the insulation surfaces. It usually is readily detectable, as there will usually be a matching point or area on an adjacent coil or surface across the air space.

4–17. REMOVAL OF OLD INSULATION

When a machine is to be rewound, it is important to remove all the old insulation without damaging the core or its interlaminar insulation. It is also important that the material used for removing the old insulation is not damaging to new coils, as it may lodge in the core interstices and subsequently leach out onto the new coils. Old insulation can be removed more easily with high-power solvents such as some of the acids or strong alkalies, but it is quite difficult to remove such materials completely from the core. The best and safest way of removing insulation is mechanically to strip out as much of the old winding as can be conveniently removed and then to scrape out remaining particles without burring or scuffing the edges of the laminations. **The use of a file should be avoided, as it may burr the laminations, which will result in excessive iron losses subsequently.** If there are any remaining parts of insulation which cannot be removed, the core can be baked in a high-temperature oven at a temperature not to exceed 200 C for 12 hours. Subsequently the remaining particles of insulation and varnish should be scraped by hand and the varnish removed from the surface by wire brushing. After this procedure the core should be cleaned with solvent and dried in accordance with Sec. 5–20 and subsequent instructions.

4–18. BEARING INSULATION

On large a-c machines bearing currents are sometimes encountered which may be damaging to the shaft journal and bearing

surface. In order to prevent such damage the bearings on some motors and generators are insulated. It is necessary only to insulate the bearing at one end in order to interrupt the circuit formed by the shaft through the two bearings and returning through the frame. Experience has indicated that it is desirable to provide some form of bearing insulation wherever the possible ampere turns around the shaft exceed a value of 3,000.

The primary insulation is either in the bearing pedestal or in the bearing support pads. Where the pedestal is insulated, a thin sheet of insulation such as fibre or melamine laminate is used as illustrated in Fig. 4-15. Thicknesses of ⅛ to ¼ inch are common. Dowels and bolts must also be insulated with insulating tubing and washers. If insulated pedestals are used, then the oil piping and water-cooling lines, if used, must have insulated couplings in them. Where the bearing pad itself provides the insulation, as on modern turbine generators, a molded insulating channel of about ⅛ inch thickness is commonly used. This also requires the use of insulated bolts and dowels, but the oil piping and water-cooling lines do not require insulation.

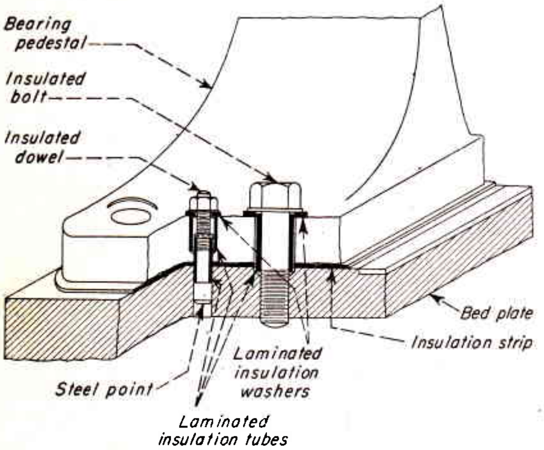


Fig. 4-15. Typical bearing insulation on large a-c generator. (*Westinghouse Electric Corp.*)

The voltages encountered in insulated bearings are quite low, and spacing insulation is usually considered adequate if a sufficiently high resistance is maintained under operating conditions.

4-19. SOLDERING AND BRAZING

Although not directly associated with insulation, soldering methods and materials have an important effect on insulation. The use of improper soldering methods and the wrong fluxes may destroy insulation or may actually render it conducting so as to produce service failures.

Solders. Most solders used in making connections in electric machinery are based on tin or lead and usually contain portions of each. Reference to the lead-tin solder constitution diagram, Fig. 4-16, shows the ratio of tin and lead in various solders in relation to the "liquidus" and "solidus" temperatures. A pure tin solder melts at 232 C and has no mushy state. As small percentages of lead are added to tin solder, the melting temperature rapidly decreases and instead of a sharp melting point there is a mushy state as shown in the diagram. There is a "solidus" temperature below which the solder is completely solid and a "liquidus" temperature above which the

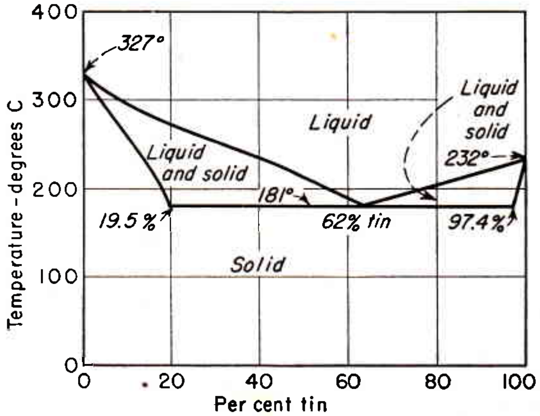


Fig. 4-16. Lead-tin constitution diagram for common solders.

solder is all liquid. Between the liquidus and solidus temperatures there is a mushy range where both liquids and solids are present. It will be noted from the diagram that this mushy range disappears in a solder containing 62 percent tin and 38 percent lead. This is called the "eutectic point" of lead-tin solders, where there is an intermediate sharp melting point. At the other end of the tin-lead ratio, 100 percent lead melts at 327 C.

This diagram indicates that only a slight contamination of lead in tin (2.6 percent) reduces the solidus point so that the solder becomes mushy at 181 C. Solders having a softening temperature of 181 C are entirely satisfactory for class A insulation. However, it is generally undesirable to use them in class B insulation where the joints are embedded in the coil or have sufficient heating to raise their temperature above the surrounding metal. For class B apparatus pure tin solder is preferable because it melts at 232 C. For class H insulation there are special lead-tin alloys at the high-lead end of the scale. Usually these contain about 10 percent lead (Pb) and around 90 percent tin (Sn) with the addition of small quantities of other metals.

Fluxes. Where soldering operations are performed adjacent to insulation, it is very important that the soldering flux used not be a conducting material or one which may become conducting when exposed to moisture. For this reason it is a **must** that only neutral fluxes, based on rosin, be used and that no acid fluxes be employed. Neutral fluxes are available made of rosin and alcohol or rosin and petrolatum. Other types of solvents may be used for rosin. Although rosin fluxes are not so active as acid fluxes, they can be used satisfactorily and present no insulation hazard. Acid fluxes will leave a residue which damages insulation and corrodes metal. They also contain metal salts which are ionizable and become highly conducting in the presence of moisture. Examples of strong acid fluxes which **should not** be used are zinc chloride, hydrochloric acid, and ammonium chloride. All are **acid** fluxes containing ionizable material which is harmful to insulation. **Their use should be avoided.** They should be used only for pretinning bare copper which can be thoroughly washed and rinsed before insulation is applied to it. Many mysterious insulation troubles, especially surface conductivity, can be traced to the use of acid fluxes.

Brazing. Certain special types of electric machines have windings connected by phos-copper brazing or silver solders (another form of brazing). These machines are unusual, and very special equipment (such as electric brazing transformers and tongs) is required in order to form such joints. The brazed joints are capable of withstanding very high temperatures and are finding wider usage. However, when joints are brazed, the possible damage to the adjacent insulation from overheating must be considered. It is generally inadvisable to braze joints near class A insulation. Generally some precautions are required to keep class B insulation cool during brazing adjacent to it. Class H insulation has such good thermal endurance that frequently brazing operations can be performed adjacent to it with little likelihood of damage.

4–20. CORE INSULATION

Voltages are generated in the magnetic core of an electrodynamic machine wherever there is rapidly changing magnetic flux. The core of an armature is always subjected to this condition during normal operation of an electric machine. This usually requires breaking up the conduction circuits in the

magnetic structure by lamination of the magnetic material and inserting some form of insulation or high resistance between laminations. An early form of such insulation consisted of placing thin sheets of paper between adjacent laminations. Subsequently, a varnish treatment of punchings was used which has been designated as "core-plate enamel." The voltage generated within a magnetic core is determined by the rate of flux change. This in turn is largely dependent on speed of rotation and bore diameter. The actual voltages encountered will vary from less than 1/10 volt per inch of core length on small machines to more than 5 volts per inch of core length on large high-speed generators or motors.

The most widely used form of punching insulation is the so-called core-plate enamel which employs an organic varnish finish baked on individual punchings. This is a thicker type of insulation, having only fair space factor. It adds about 2 percent to the thickness of a 0.014-inch-thick lamination.

An inorganic type of punching insulation used by some manufacturers for nearly 20 years consists of a water-glass coating on punchings. This has good temperature stability but requires sealing of the punching edges against moisture, as water glass is somewhat hygroscopic. Water-glass lamination insulation has good space factor, as it adds ½ to 1½ percent to the thickness of an 0.014-inch-thick punching.

Another form of punching insulation is obtained by oxidation of the lamination surface through heating in a controlled atmosphere. This is the thinnest type of surface treatment, as it utilizes only approximately ½ percent or less of the thickness of 0.014-inch-thick lamination. On many designs of small apparatus operating at low speeds no intentional lamination treatment is applied. The designs work, as the voltage generated is low and the area of punchings is small and because an inadvertent oxidized film is present on most magnetic sheet material.

A recently developed insulation for laminations uses a phenolic thermosetting resin filled with an organic silicate. The organic silicate decomposes to a mineral silica to provide positive separation between laminations in case the organic resin is destroyed by overheating.

The resistivity of the punching insulation varies quite widely, depending upon the process used and the conditions under which the material is tested. The observed value of resistivity is dependent upon the width of the sheet in which the tests are made as well as upon the type of insulation employed and the processing. Acceptable values of resistivity range from 0.01 ohm to several thousand ohms per unit area (square centimeter) per lamination. The median value is usually a few ohms per centimeter square per lamination. It is important to recognize that study on individual resistivity tests yields results that have a logarithmic distribution of resistivity values. Therefore, acceptable resistivities will have a very wide range and will vary from the median by a factor of from one-tenth to ten times the median in most cases.

5. Varnish-treating Processes; Cleaning and Drying; Tropical Service and Storage

Most classes of electrical insulation require the use of varnish or other impregnating compounds to make them satisfactory for service conditions. Class O insulation is the only one which does not require such treatment, and it is intended for low-temperature operation where it is not exposed to high humidity. All other classes of insulation as defined by the AIEE, ASA, and NEMA as well as Navy standards require (by definition) the use of a suitable resinous treatment except where the insulation is immersed in a fluid insulator, such as oil. Paper, cotton, asbestos, synthetic textiles, fibrous glass, and mica all have their insulating properties improved when they are bonded and their interstices are filled with a resinous substance. **Without such treatment, these materials have dielectric breakdown values approximately the same as air of the same spacing.** In addition considerable improvement is obtained in the electrical properties of insulations when their surface is fortified with a satisfactory varnish film. Such treatment of insulation interstices and surfaces is of particular importance on apparatus subjected to high humidity, oil, dust and dirt, corrosive atmospheres, and salt spray. Furthermore, varnish treatment actually contributes to increased insulation life. This fact is recognized by the permissible increase in operating temperature for class A over class O insulation. This is entirely attributable to the treatment, as the component insulations are identical.

Apparatus for shipboard service is particularly in need of adequate varnish treatment because of the presence of high humidity, salt atmosphere, and oil. Similar need exists in electrical equipment for many industries, such as railways, chemical factories, steel mills, coke furnaces, mines, and food-processing plants. Experience has demonstrated that a thorough varnish treatment provides essential insurance for

satisfactory operation under adverse circumstances. The degradation of such varnish treatment will be observed by the loss of moisture resistance of the insulation. This should be a warning indicating the necessity for retreatment to restore the moisture-vapor barrier.

Sections 5–1 through 5–5 are specifically applicable to the varnish treatment of new windings and should be of primary interest to equipment manufacturers and to shipyard repair forces engaged in the rebuilding of electrical equipment.

5–1. INSULATING VARNISH CHARACTERISTICS

The application of insulating varnishes to coils for use in electrical machinery may be divided into three classifications.

1. The first class is the application of varnish by brushing or flowing to the slot portion of the coil in order to bond the conductors together. This is often called "bakelizing" or bonding. This operation is necessary in order to obtain a rigid straight section on certain types of coils. This facilitates the application of the ground insulation and ensures that the conductors remain stationary with respect to each other during the manufacturing cycle and during operation in the machine. Usually this operation is performed only on armature and stator coils.

2. The second class is the application of varnish to a completely or partially treated coil by means of a vacuum-pressure impregnation cycle. This is commonly called "impregnation." The purpose of this operation is to fill as completely as possible and practical all voids which exist in the ground wall. A further purpose is to bond or consolidate the component parts of the ground insulation.

3. The third class is the application of a varnish to a partly or completely insulated coil by means of a dipping operation. The main purpose of this operation is to apply a protective coating to the surface of the coil. A further purpose may be to obtain as much penetration into the interstices of the coil as possible. This applies only to coils which have not been impregnated. An additional purpose is further to bond the component parts of the insulation wall. The film or protective coating is necessary in order to prevent the entrance of moisture, gases, and foreign objects into the insulation wall throughout the life of the coil.

Considering these three applications, the following general properties are desired in an insulating varnish. It must exist in a fluid condition in order to facilitate application. When properly processed, it must have film-forming and adhesive properties. The film must be relatively inert to chemical reaction and must present an effective barrier to the passage of moisture, gases, and foreign substances. The film must be relatively resistant to abrasion. And above all, it must be a nonconductor of electricity. Of course, for a specific application additional properties may be desired.

It is within the classification of materials known as organic compounds that the desired characteristics are found. However, not all organic compounds will do. The desired properties are found in organic compounds of high molecular weight. This particular type of compound is known as a "polymer." The term polymer is derived from the Greek *polus* meaning "many" and *meros* meaning "part." A polymer is defined as a substance in which a structural unit occurs repeatedly. Polymers which have more than one repeating structural unit in the same chain are called "copolymers." The term "high polymer"

merely denotes a polymer of molecular weight of the order of thousands rather than one of the order of a few hundred, to which the term "low polymer" is applied. Polymers may be broken down into various classifications. However, the most common basis is whether the polymer is thermosetting or thermoplastic. A thermosetting polymer is one which forms a three-dimensional network upon curing. Such polymers are insoluble and infusible. A thermoplastic polymer is one which forms only a linear molecular structure. Such polymers are generally soluble in the proper solvents and are fusible. Because the thermoset polymer is the more stable and inert of the two, a large percentage of the insulating varnishes are of this type.

Most thermoset polymers exist in three stages, namely, the A stage, the B stage, and the C stage. In the A stage the polymer is rather fluid, of a relatively low molecular weight, and soluble and fusible. In the B stage, the polymer is more viscous, of a higher molecular weight (*i.e.*, the molecule is larger), being insoluble but plastic and fusible. In the C stage, the polymer is in the solid state, of a very high molecular weight, and insoluble and infusible. It should be recognized that there are some polymers which pass very rapidly from the A stage to the C stage and have no practical B stage. These are usually those resins which are highly exothermic (giving off considerable heat while reactive). Many ways are known of polymerizing or forming these larger molecules from smaller ones. Generally, heat or oxygen or both are needed.

Nearly all the insulating varnishes are solutions of thermosetting polymers (often called resins) in a solvent such as petroleum naphtha, toluol, or xylol or mixtures of these. However, there are exceptions which will be discussed later. The resin usually has been carried to a point which is somewhere between the A and B stages. Generally speaking, the percentage of nonvolatile or solid matter commonly ranges from 45 to 60. All the resins used in insulating varnishes either occur naturally or are synthetic. Furthermore, they polymerize, or "set up," by air drying or by baking. To speak more specifically of insulating varnishes, there are many types, phenolics, alkyds, oleoresinous, asphalt, oil-modified phenolics, oil-modified alkyds, and asphalt oil as well as the recently developed silicone varnishes.

Tests on insulating varnishes are performed according to ASTM Standards on Electrical Insulating Materials D115, and Navy Specification JAN–V–1137. The results obtained from these tests are values that are primarily relative with respect to other varnishes. The absolute values are difficult to interpret in terms of service requirements. The procedure for each test will not be dealt with in detail here, but their significance will be reviewed briefly.

1. Viscosity is a fluidity test used primarily as an identity check, but also of interest in determining application conditions to produce a suitable film.

2. Specific gravity is a quick and convenient relative measure of resin content for a particular varnish.

3. The percentage of nonvolatile matter by weight indicates the usable resin content.

4. Drying time gives a relative indication of the speed of solvent evaporation (and sometimes curing speed) under controlled conditions.

5. Dielectric tests are made on cured films, usually on copper panels or paper. These are made on the films both dry and after immersion in water for 24 hours.

6. Heat endurance or "flex-life" tests are

made by coating a controlled film thickness on a copper panel and determining the time-temperature relation before the film cracks when bent around a ⅛-inch-diameter mandrel. This is a relative measure of the thermal endurance of the varnish under flexural stress.

7. Oil-resistance tests indicate the suitability of the varnish film for use in applications where exposed to oil.

8. Insulation-resistance and salt-water tests evaluate the resistance of films to fresh water or sea water, as well as indicating whether the varnish forms pinhole-free films.

It should be recognized that varnish films are not permanent. Certain physical and chemical changes take place in varnish films owing to aging at elevated temperatures. The most significant changes which occur in varnish films on heating are pronounced shrinkage, reduction in weight, and increased stiffness. The chemical reactions which lead to this deterioration are further polymerization, condensation, oxidation, and thermal decomposition. The exact part each plays in destroying the continuity of the structure of any given varnish is not known. When it is known which of these factors is primarily responsible for the deterioration, an insulating varnish may be formulated which will be relatively more permanent. This should be borne in mind when selecting an insulating varnish for a particular application. The selection should not be on initial properties alone but should be based on the expected useful life of the machine.

5–2. VARNISH TREATMENT OF COILS

Coils which are to be treated separately before being assembled in a machine can be processed in several ways. The manner selected depends somewhat upon the construction and ease of varnish penetration as well as upon the type of impregnant chosen and the thoroughness of treatment desired. The simplest form of treatment is the dipping process. A coil which contains only **porous** insulating material with **easily penetrated voids** can be treated after completion by simply immersing it in varnish and allowing it to soak until varnish has penetrated the voids. Figure 5–1 shows such a treatment being applied to coils. A more complex coil which contains wrap-

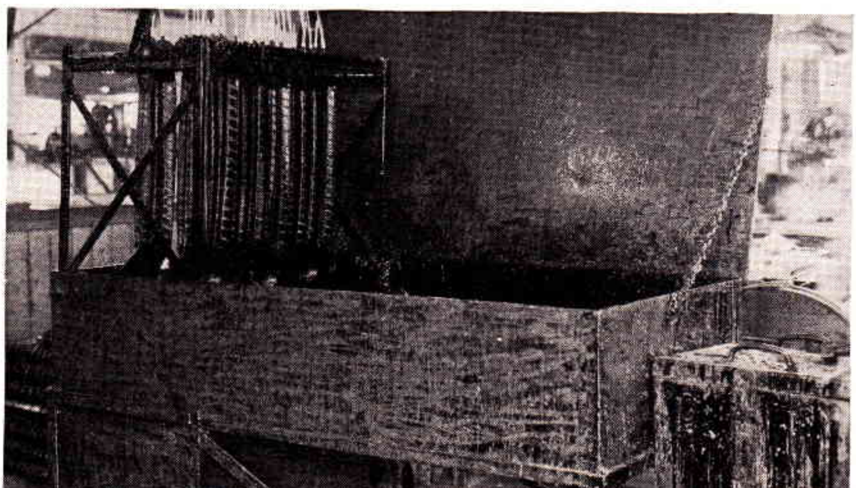


FIG. 5–1. Treating coils by dipping. (*Elliott Co.*)

per or multiple layers of tape is difficult to treat thoroughly by simple immersion processes. Such coils may be treated by multiple dipping. This usually involves a dipping process on the formed coil before the outer insulation is applied plus additional dipping after the outer insulation layers are applied. It is generally desirable to bake the coils after each dipping process. However, in some cases air drying of the individual dips may be satisfactory, particularly if the coil is to be baked after it has been assembled in the apparatus.

For the most complete impregnation of insulation voids, vacuum-pressure impregnation is employed. This also is usually a single-process treatment for a finished coil and, therefore, is more economical than multiple dipping. By this process the coils are placed in a vacuum-pressure tank such as illustrated in Fig. 5-2. The coils may be preheated or not depending upon the type of varnish employed. After the lid is closed, a vacuum is drawn on the tank removing nearly all the air and moisture from the tank. While the tank is still evacuated, the varnish (or other impregnant) is admitted to the tank until it covers all the coils. Then gas pressure is applied to the varnish for a considerable period, allowing the varnish to penetrate into the coil interstices under hydraulic pressure. This is the most thorough method of assuring a good fill of coil and insulation voids. It should be noted that so-called "100 percent impregnation" is quite difficult of attainment. It is impossible where a solvent-type impregnating varnish is used, as voids are left when the solvent is evaporated. Even with solventless impregnant some minor voids can be expected due to trapped gases and runout of the impregnant during draining and curing.

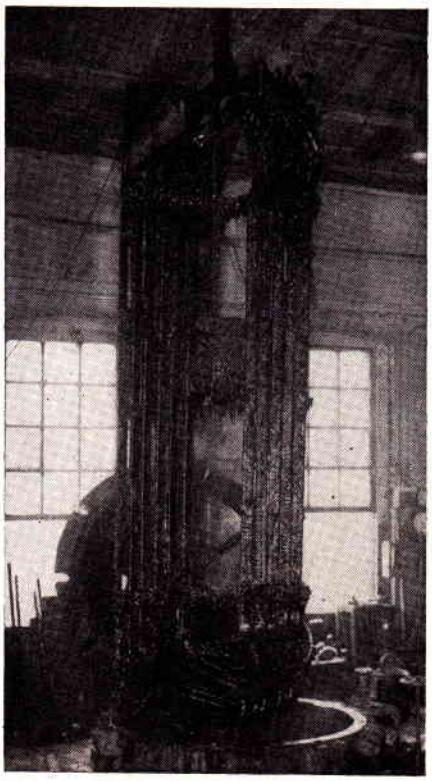


Fig. 5-2. Impregnation system for treating coils by vacuum and pressure. (*Elliott Co.*)

Before applying varnish treatment to coils it is desirable to ensure that they are free from moisture or excessive quantities of solvents. Therefore predrying prior to varnish treatment is quite often employed. Whether or not the hot coils are immersed in varnish depends upon the type of varnish employed. It is generally preferable to cool coils to 40 C (104 F) after predrying before immersing in the varnish, as heat-reactive varnishes may be set up (polymerize) prematurely. However, certain processes with particular varnishes (usually those requiring long or high-temperature bake) do involve the placing of heated coils in varnish. The disadvantages of such processes are accelerated aging of the varnish and rapid evaporation of the solvent. For very viscous liquids improved penetration and fill may be obtained.

5-3. TREATING WOUND APPARATUS

There are two distinct classes of wound apparatus in so far as treatment is concerned. This depends upon whether or not the coils have been previously treated separately. The treatment of these two types of wound apparatus is different as far as the varnish treatment of the assembly is concerned.

The treatment of windings which contain coils previously treated should accomplish the following:

1. Provide a continuous varnish film over that part of the coils, core, band, and miscellaneous surfaces that are exposed. This film should be relatively impervious to moisture, gases, foreign substances, and oil. In addition, it should be as smooth and glossy as possible in order to minimize the collection of dust, dirt, or other substances on the surface of the winding. As much penetration as possible of the varnish into the interior is desired, but generally on this type of winding very little is possible.
2. Repair, by means of this varnish film, all previously treated exposed surfaces that may have been scuffed in handling or winding.

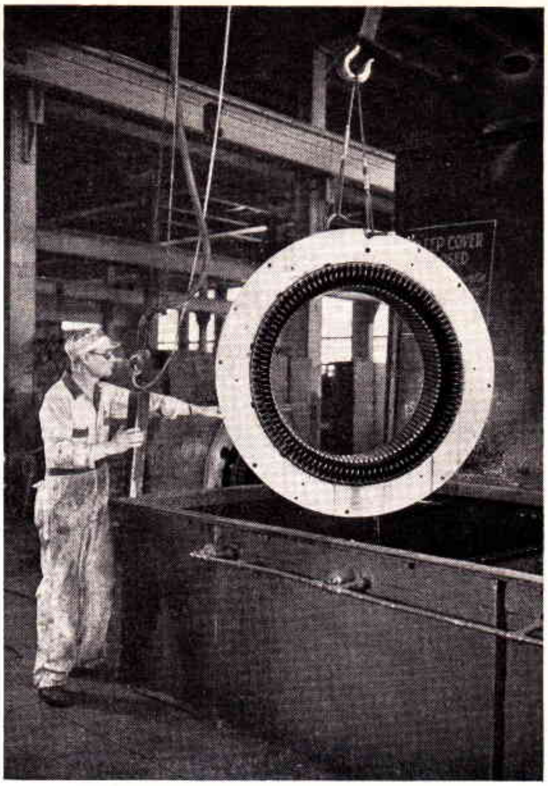


Fig. 5-3. Dipping wound stator. (*Allis-Chalmers Mfg. Co.*)

3. Further bond the component parts of the winding together, especially to bond the coils to the core.

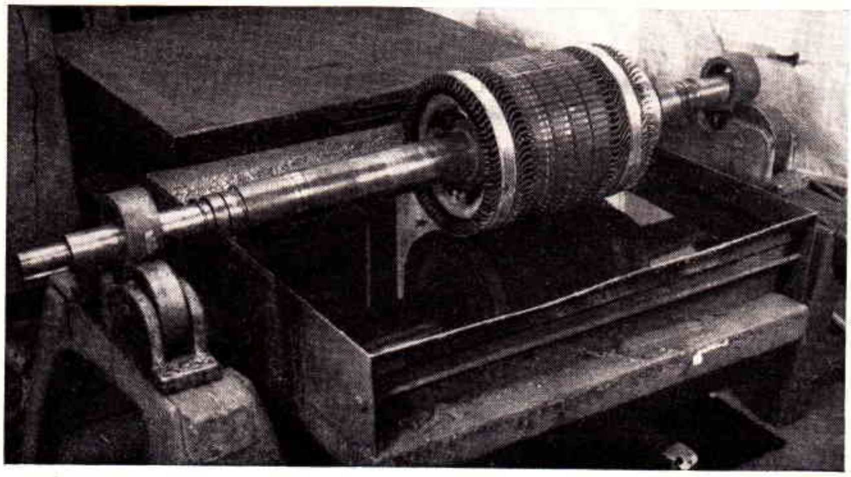


Fig. 5-4. Rolling and flowing treatment of d-c armature. (*Elliott Co.*)

Figure 5-3 illustrates processing a d-c armature by dipping, and Fig. 5-4 shows how a larger d-c armature is treated by rolling it in a shallow varnish tank.

On windings the coils of which have not been previously treated, the treatment of the windings should accomplish the following:

1. Provide an internal varnish treatment by means of an impregnation operation. This treatment as far as the coils are concerned, in this type machine, should approach that accomplished by an individual coil treatment previous to winding. It must be remembered that, no matter how well the impregnation is carried out, the varnish will not penetrate into any section of the winding in which the physical pressure on the insulation is greater than the pressure exerted by the impregnating medium.

2. In addition, this type of finish treatment should provide a continuous varnish film over the exposed surfaces and bond the component parts of the winding together, fulfilling the other requirements of treatment for apparatus wound with pretreated coils.

Figure 5-5 shows a method of dipping small a-c motor stators (untreated coils).

5-4. INSPECTION AND TEST OF VARNISH

It is important that varnish be used at the proper consistency in order to obtain a suitable film on the work. It is therefore essential that each variety of varnish, for each specific application, be suitably controlled in order to obtain consistent results. Generally there will be a concrete recommendation concerning the application characteristics of each varnish for a particular

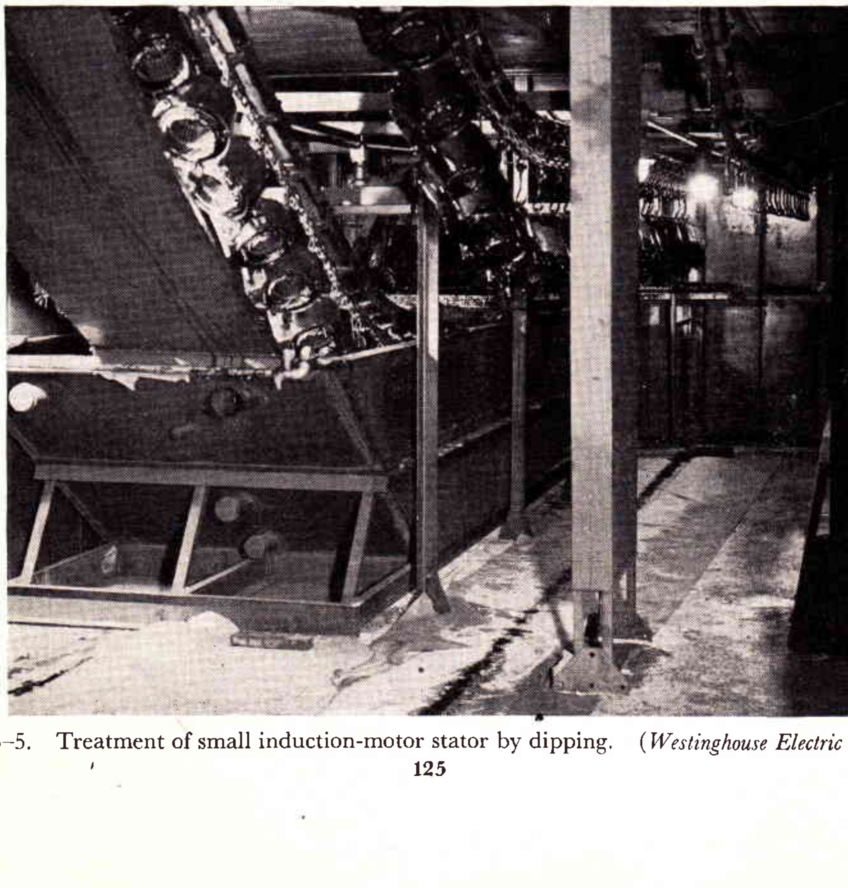


Fig. 5-5. Treatment of small induction-motor stator by dipping. (*Westinghouse Electric Corp.*)

use. This is generally a combination of specific gravity and viscosity. Specific gravity is an approximate check for body or percentage of nonvolatile matter. In addition it is necessary to take the temperature of the varnish and make suitable corrections for temperature to a base temperature (usually 25 C). Specific gravity is observed

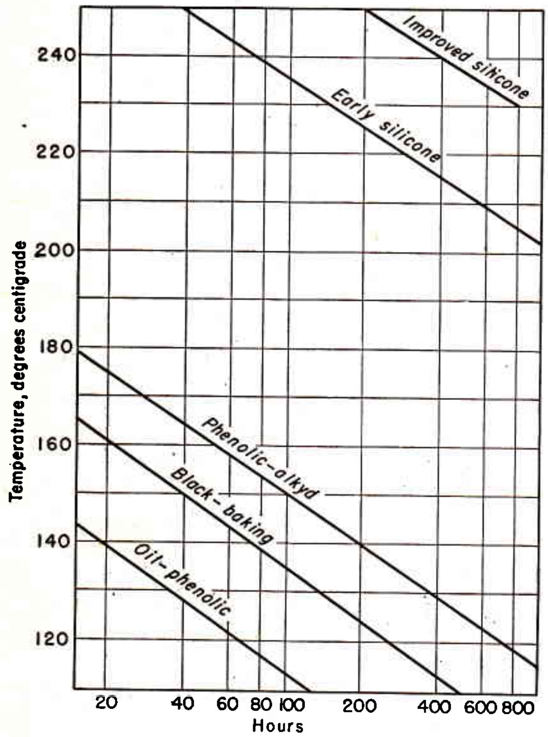


FIG. 5-6. Thermal endurance of varnish (flex life) at various temperatures.

by a standard hydrometer, and viscosity is observed with one of the conventional cup-type viscosimeters or by means of the rough viscosity cup described in subsequent sections. In checking the condition of varnish in a tank or in a container the following steps should be taken:

1. Be sure that the varnish is suitably mixed so that it is of uniform consistency.
2. Determine the viscosity as described in Sec. 5-5.
3. Determine the specific gravity with a hydrometer.
4. Measure the temperature of the varnish (preferably in degrees C).
5. Refer to the curve of Fig. 5-7, and determine the temperature-correction factor by which the observed viscosity shall be multiplied in order to correct the viscosity to the common reference temperature.

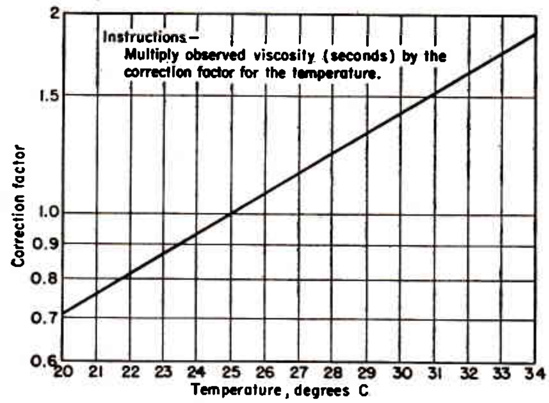


FIG. 5-7. Temperature correction of varnish viscosity.

6. Correct the specific gravity to the common reference temperature by adding 0.0007 to the observed specific-gravity value for each degree C above reference temperature or subtract for each degree below the reference temperature.
7. The corrected viscosity and corrected specific gravity to a common temperature base (25 C) are comparative data which indicate the condition of the varnish. As varnish ages, its viscosity will increase rapidly for a given specific gravity (or body). Since viscosity is the most important application characteristic, it is customary to thin the varnish to a specified viscosity. As varnish ages, the viscosity increases and relatively more thinner is required to maintain the viscosity. This results in a reduction in specific gravity and resin content with respect to the viscosity.

In controlling a tank of varnish it can be assumed that the solid resin content (percent nonvolatile) is measured by the specific gravity and that there is a direct relationship between them. To determine the viscosity, resin content, and specific-gravity relationship of a batch of varnish, all three values should be measured in the "as-received" condition. The varnish should then be thinned, with the proper thinner, to a lower consistency than it will normally be used, and the viscosity, resin content, and specific gravity should again be determined. When viscosity and specific-gravity values have been corrected to a base temperature (usually 25 C), the data can be plotted on a sheet of semilogarithmic graph paper for future reference as shown in Fig. 5-8. A parallel curve should then be drawn to establish the limits for scrapping old varnish. This limit is usually established by experiment for each varnish. However, a reduction of 6 percent in nonvolatile or 0.030 in specific gravity for equal viscosity is generally an indication of possible trouble. Another way of looking at this change is that the varnish shown in Fig. 5-8 has increased in viscosity (at 50 percent nonvolatile and 0.900 specific gravity) from 27 to 80 seconds. This is indicative of significant chemical changes in the resin. It is preferable to scrap questionable varnish, as the film-forming ability of a resin cannot be determined by superficial observation. If the desired viscosity range for this varnish is 50 to 100 seconds, the usable range is defined in Fig. 5-8 by drawing parallel lines at the 50- and 100-second levels.

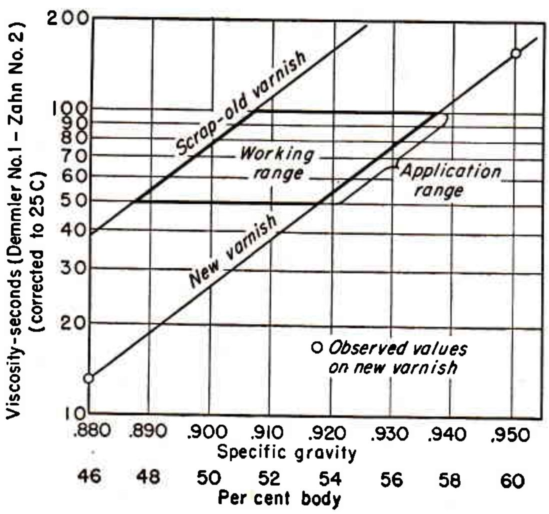


FIG. 5-8. Varnish control curve, showing viscosity, solids, and specific-gravity relation of new and old varnish.

5-5. MEASUREMENT OF VARNISH VISCOSITY

Viscosity is a measure of the resistance of a fluid to flow. Simple viscosity-measuring instruments are usually in the form of a cup, and the viscosity of a fluid is expressed as the time (in seconds) required for a given volume to flow through a specific orifice. The No. 1 Demmler cup and the No. 2 Zahn cup are typical examples which give equivalent values. The Dow Corning No. 2 cup is commonly used for measuring the viscosity of silicone varnishes. The

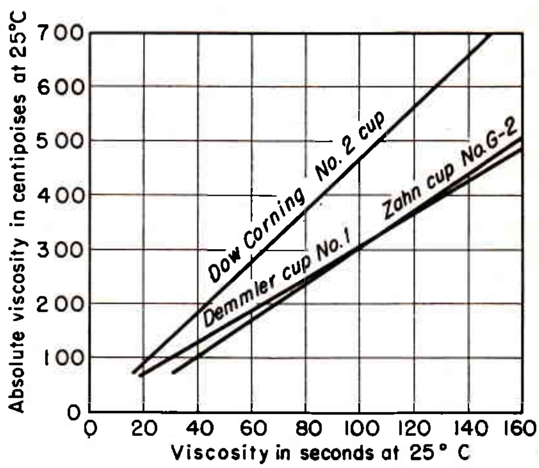


FIG. 5-9. Relation between absolute viscosity in centipoises and viscosity in seconds as measured with various cups.

curve of Fig. 5–9 shows the relation between viscosity in seconds for several cups in common use and the absolute viscosity in centipoises.

For approximate viscosity measurements in the absence of conventional instruments, use a small can (about ½ pint capacity) with a small hole (not more than ⅛ inch diameter) in the bottom. Calibrate by filling the can with fresh water and observing the time required for the can to empty. Then dry the can, and repeat with varnish. Water has a viscosity of 7 seconds by the Demmler No. 1 or Zahn No. 2 cup. Therefore, from this information, the viscosity of a liquid can be approximated by the formula

$$7\frac{S}{R} = V$$

where R = reference value, the observed time for water, seconds.

S = observed time for varnish, seconds.

V = seconds viscosity—No. 1 Demmler cup or No. 2 Zahn cup.

Ordinarily varnish for dipping apparatus should be 7 to 14 times the viscosity of fresh water by this crude test at a temperature of 22 to 30 C (72 to 86 F).

Varnish which is above the desired viscosity should be thinned by using the thinner specified in Sec. 5–42.

5–10. GENERAL INSTRUCTIONS ON CLEANING INSULATION

Sections 5–10 through 5–39 are specifically applicable to shipboard maintenance (cleaning) of electrical windings and cover the general instructions to be followed by all repair forces in the cleaning, drying, and varnish treatment of windings and equipment.

The importance of keeping all insulation clean cannot be overemphasized. Dust, dirt, and foreign matter (carbon, copper, mica, etc.) tend to block ventilation ducts and to increase resistance to the dissipation of heat, resulting in local or general overheating. If the particles are conducting or form a conducting paste through absorption of moisture or oil, the windings may eventually be short-circuited or grounded. Abrasive particles may puncture insulation. Iron dust is particularly harmful, since the dust is agitated by magnetic pulsations.

It should be recognized that the accumulation of oil on the surface of windings has several detrimental effects. In the first place, it forms the base for the accumulation of numerous contaminants which will be discussed at length in Secs. 7–40 through 7–44. Second, many varnishes are not completely oil resistant, and their films are somewhat softened by the continuous presence of oil on their surfaces. **This effect is particularly noticeable with the asphalt-base oleoresinous varnishes such as grade BB.** The removal of traces of oil from a winding is quite difficult even where careful cleaning methods are employed with solvent. If the varnish film has degraded from excessive heat, oxidation, or softening of the film by solvent action of the oil, dirt and oil may penetrate into the insulation. The act of cleaning may force such dirt into existing crevices in the varnish film. It is therefore desirable to choose finish varnishes which are highly resistant to oil and solvent attack as well as having good thermal endurance and essential moisture resistance. The synthetic resin varnishes have all these desirable characteristics. These are available as Navy grade CB and **should be used in preference to other types of varnish for treating windings in Navy service.**

For these reasons, equipment should be cleaned both externally and internally, being particularly careful to keep all air ducts clean. There are four acceptable methods of cleaning insulation, namely, wiping, use of compressed air, use of suction, use of a solvent.

5–11. *Cleaning by Wiping*

Wiping is effective in removing loose dust or foreign particles located in accessible parts of the machine only. The surfaces should be wiped with a clean dry rag that will not deposit lint. Cheesecloth is recommended for this purpose. When wiping, do not neglect such parts as the end winding, mica cone or V-ring extensions at the commutator of d-c machines, slip-ring insulation, terminals and terminal insulation, connecting leads, etc.

5–12. *Cleaning by Use of Compressed Air*

The use of compressed air is effective in removing dry, loose dust and foreign particles particularly from such inaccessible locations as in air vents in the armature punchings. Only compressed air that is clean and dry should be used. Air pressure up to 30 pounds per square inch may be used on motors or generators of 50 horsepower or 50 kilowatts or less. Pressures up to 75 pounds per square inch may be used to blow out machines which are over 50 horsepower or 50 kilowatts. Where air lines carry higher pressure than is suitable for blowing out a machine, a throttling valve should be used to reduce the pressure. Always allow any accumulation of water in the air pipe or hose to be thoroughly blown out before turning the air blast on the machine. Compressed air should be used with caution, particularly if abrasive particles are present, since these may be driven into the insulation and puncture it or be forced beneath insulating tapes. Compressed air should be used only after the machine has been opened up on both ends so as to allow a path of escape for the air and dust. **It should be noted that the use of compressed air will prove of small benefit if the dust is not suitably removed from the machine.** The most suitable method is to attach a suction blower to an opening in the opposite end from the air jet to remove the dirt-laden air.

5–13. *Cleaning by Use of Suction*

The use of suction is preferable to the use of compressed air for removing abrasive dust and particles, since there is less possibility of damaging insulation. A flexible tube attached to the suction side of a portable blower will make a suitable vacuum cleaner which can be used for this purpose. The use of a suction blower attached to take suction adjacent to the commutator is particularly desirable to draw loose particles away from windings when stoning commutators or seating brushes. Grit, iron dust, and copper particles should be removed only by suction methods whenever possible.

5–14. *Cleaning by Use of Solvents*

The use of solvents for cleaning electrical equipment should be avoided in so far as practicable. However, when it is necessary to remove hard or pasty deposits of dirt or foreign matter from the surfaces of insulation, an acceptable solvent furnishes the only practicable solution of the problem. Solvents are particularly necessary for removing grease and pasty substances consisting of oil and carbon or dirt.

The solvent recommended for shipboard use in cleaning off such deposits is carbon

tetrachloride. While this is an effective cleaning agent, it has the following disadvantages and should, therefore, be used only when necessary:

1. Carbon tetrachloride is toxic, and normal safety precautions should be observed when this solvent is used (see Sec. 5-44).

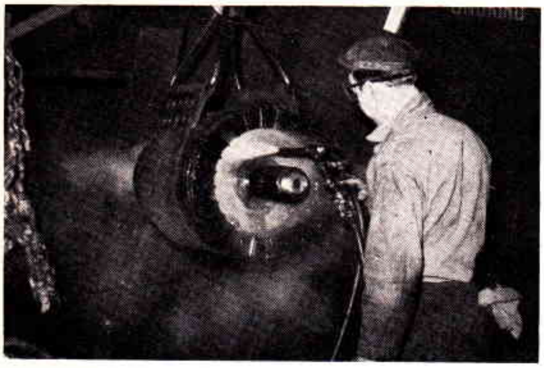


FIG. 5-10. Cleaning windings to remove surface contaminants prior to revarnishing. (*Westinghouse Electric Corp.*)

2. Carbon tetrachloride is very corrosive in its action on metal and may prove injurious to certain varnishes used to coat electrical insulation. Before using carbon tetrachloride, apply it to a small area or sample of the insulating material in accordance with the following instructions. If it injures the insulation, use water for cleaning as described in Sec. 5-14 (4).

3. Carbon tetrachloride is detrimental to good commutation and should be kept from coming in contact with brushes or with the commutators of d-c machines. There is also some reason to believe that commutation may be adversely affected by carbon tetrachloride vapor in the atmosphere even when the liquid does not come in direct contact with brushes or commutators. For this reason alone, it is desirable to use carbon tetrachloride only when necessary. When carbon tetrachloride must be used, it should be applied by moistening a lintless cloth with the fluid and slightly rubbing the surfaces to be cleaned. Allow the surfaces to dry, and repeat the process if necessary. Do not spray carbon tetrachloride on windings. It will collect in pools, soften the insulation, and do more harm than good. When used on a cloth, it loosens the dirt so that it can be wiped off with a cloth or, if necessary, removed with a wooden scraper or fiber brush. After the cleaning, the surfaces should be dried thoroughly by wiping with a clean, dry cloth.

4. Clean fresh water, preferably warm or hot, may also be used for cleaning purposes. The use of water is recommended as an emergency substitute for carbon tetrachloride, and its application must be followed by a thorough drying of the insulation before placing the equipment in service. A relatively neutral detergent may be added to water to aid in removal of grease. Cleaning with warm water and a neutral detergent is recommended for class H insulation in preference to other methods because of the detrimental effects of some solvents on silicone varnishes.

5. Dry-cleaning solvent (Stoddard solution) may also be used for cleaning electrical equipment at Naval shipyards which are equipped to revarnish electrical equipment. It must not be used aboard ship because of certain fire and explosive hazards. For shore use, it can be safely used if the necessary precautions in regard to the use of inflammable materials are observed. Adequate safeguards should be used also to protect personnel from the slightly toxic effects of the solvent as well as to protect against skin dermatitis, which can result from contact with the solvent (see Sec. 5-43 on specification of this solvent).

Special Notes. **Alcohol will injure most types of insulating varnishes and should**

not be used for cleaning electrical equipment.

Solvents containing gasoline or benzine should not be used on board ship for cleaning purposes under any circumstances.

5–20. DRYING INSULATION

Moisture absorbed by insulation or condensed on its surfaces causes deterioration and may result in short circuits or grounds. The dielectric strength of the insulation is lowered temporarily while moisture is present and may be lowered permanently if deterioration of the insulation occurs. For these reasons moisture should not be allowed to accumulate and equipment should not be placed in service without first drying out the insulation, when repaired, in accordance with one of the following methods:

1. Drying insulation is a necessary step in some procedures for reconditioning electrical equipment which has been submerged in or splashed with water. It may also be necessary at times to dry equipment which has not been submerged in or splashed with water but which has absorbed moisture from the air as a consequence of having stood idle for a considerable period of time. The best method to follow in each specific case depends upon local conditions and the facilities and equipment available.

2. In general, heat and the circulation of dry air (or the application of a vacuum) are necessary to remove moisture from insulation. Heat may be provided by either of two methods or by a combination of both. One method is by external application. The second method is by circulating current at low voltage through the conductors to provide the necessary heat internally. This second method should not be employed for drying water-soaked insulation until it has been partially dried by the first method.

3. Whatever the method of heating, a close check must be kept on the temperature of the insulation. This may be done by means of temperature detectors, either permanently or temporarily installed, or by thermometers placed so that they can be easily read at the hottest spots on the equipment. Heat application should be steady. Interruption of a heating operation to the extent that the apparatus approaches ambient temperature may allow moisture to condense on the insulation and retard the progress of the drying. Drying cannot be hurried; many hours or even days may be necessary to secure satisfactory results. Fire risks must be avoided, and positive air circulation provided. Ample ventilation for the escape of moisture is essential to and hastens the drying operation. It will be found impossible to dry insulation by the continuous application of heat in an enclosure filled with moisture-saturated air.

5–21. *Oven Drying*

1. Small equipment which can be moved can be dried in existing baking ovens or drying kilns, or a room or enclosure may be temporarily arranged and equipped for drying. The oven of a cooking range may be used for small parts.

2. When no existing ovens are available for drying equipment, a temporary oven can be constructed. Numerous materials are available for doing this, such as heat-insulating panels secured to suitable frames, sheet iron, brick, or concrete blocks lined with some form of insulation. Such an oven can be built around large equipment which cannot be moved, and in the case of enclosed machines the enclosure itself may serve as an oven. A cover of sheet asbestos

may be used to enclose open-type machines. A canvas or tarpaulin cover may also be used if due care is exercised to see that the heating equipment cannot set fire to the cover.

3. Electric heaters, steam coils, radiators, stoves, or hot-air furnaces can be used to supply heat. If steam is used, there must be no leaks which might introduce moisture into the enclosure. The use of open-flame heaters is not recommended. The dust, soot, and gases from them usually prohibit their use.

4. There are three important points to be remembered when drying insulation in an oven. These are:

a. The temperature must not be so high that it causes the formation of steam in voids in the insulation and results in rupture and permanent injury. The danger from this, however, is not so great as might be expected, because the heat is applied from the outside and a large amount of heat is absorbed by water before it turns to steam. With a reasonable amount of ventilation, the heat will be carried off before excessive pressures are developed in the insulation.

b. The temperature of the air in the oven must not reach values which will damage the insulation. It is recommended that the measured air temperature should not exceed 185 F (91 C) when drying class A insulation and 220 F (105 C) when drying class B insulation. It is realized that in an emergency the equipment may be urgently needed, and there is a strong temptation to obtained quicker results by using higher temperatures. In certain cases higher temperatures have been used and the insulation successfully restored to service, but there is a distinct hazard. It should be recognized that, as the temperature is raised, the risk of permanently injuring the insulation also increases.

c. Provision must be made for removing moisture from the oven. This may be done by providing openings which allow circulation of air by convection. More thorough removal of this moisture can be accomplished by forced ventilation using fans or blowers. The fresh dry air which enters the enclosure should first pass over the heaters to become heated and should then circulate over the insulation that is being dried.

5. The windings should be inspected during the drying, and the temperature lowered if there is any sign of compound running out of the coils. The softening point of different impregnants may vary considerably.

6. If a machine can be rotated as it is dried, the process may be accelerated. If it cannot be rotated continuously, frequent turning of the rotor 180 degrees is advantageous. Changing the position of any apparatus may permit the escape of entrapped water.

7. Equipment that is hot at the time submersion occurs may be particularly difficult to dry. As the machine cools off following submersion, vacuums are created in tiny pockets and water will enter joints which are so small that it is difficult to force the water back out again during drying. This is particularly true of large machines which operate at high temperatures.

5–22. *Vacuum Drying*

1. It is not always easy to drive moisture out of fibrous insulation, even at 212 F (100 C). If the facilities are available, the quickest and most effective method is by means of combined heat and vacuum. In some instances it has been impossible to recondition certain types of apparatus by any other method. It has been demon-

strated that, if apparatus to be dried is heated to the boiling point of water in a vacuum, the moisture is usually completely removed. For the most effective results the water should be vaporized, for under some conditions and with certain materials, capillary force may approximate 15 pounds per square inch. A good vacuum alone may, therefore, not be able to overcome the capillary action.

2. The boiling point of water is reduced as the vacuum is increased. Therefore, materially lower temperatures can be used for removing water in a vacuum as compared with atmosphere pressure. Temperatures less than 212 F (100 C) allow very rapid evaporation of moisture and thorough drying in a moderately good vacuum.

3. If the temperature is raised much above the boiling point, internal pressures may be created which may result in injury to the insulation. It is important, therefore, to raise the temperature slowly and control it carefully. It is recommended that the temperature of the insulation should not exceed the boiling point of water, at the particular vacuum existing, by more than 10 F.

4. When no further water comes out at a given vacuum, increasing the vacuum will result in more water being driven off and the temperature in the apparatus will decrease owing to the increased evaporation of water. Drying should be continued at the maximum vacuum obtainable until no further water is driven off. The vacuum should then be gradually reduced with corresponding increase in temperature until atmospheric pressure is reached. If insulation-resistance measurements then show that no further drying is required, the equipment is ready for any other reconditioning which may be necessary.

5. If conditions permit, drying in a vacuum may be accelerated if the vacuum is broken at intervals and clean dry air is allowed to enter the tank. In this way the new air permeates the windings, takes up moisture, and is then removed.

6. In cases where permanent vacuum tanks do not exist, various methods have been used to construct a temporary tank. If large amounts of equipment are involved, the construction of a vacuum tank will be justified.

7. Steam ejectors provide a reliable method of producing a vacuum. The apparatus for producing heat may be either inside or outside the tank, depending upon which is more convenient. If possible, it is desirable to subject the equipment to a preliminary drying and have it up to the required temperature before it is placed in the vacuum tank.

8. Spark plugs in the shell or the heads of the vacuum tank may be used for bringing out temperature-detector leads and also leads from the winding for measuring insulation resistance or for determining temperature by hot resistance without opening the tank.

5-23. *Drying with Electric Heaters*

1. Where a source of electric power is available, grids or strip heaters provide a most satisfactory means of producing heat in an oven, vacuum tank, or individual large machines. They are easily located in any desired position, and the amount of heat can readily be controlled.

2. The capacity required in the heaters will vary with the amount of equipment to be dried, degree of enclosure, amount of ventilation, etc. It is therefore impossible to give rigid rules for determining the exact size heater required. An estimate, however, may be made as follows: The approximate weight of the apparatus to be dried

should first be calculated on the assumption that it consists entirely of steel weighing 485 pounds per cubic foot. The quantity of energy required to cause an increase in temperature of the material may be found by substituting in the following formula:

$$\text{Kilowatt-hours} = \frac{3.5 \times \text{weight in pounds} \times {}^\circ\text{F rise}}{100{,}000}$$

As an example, assume that a machine weighing 10,000 pounds is to be dried at 200 F. If the ambient temperature is 75 F, an increase of 125 degrees F will be required. The amount of energy necessary to produce this increase in temperature will be $3.5 \times 10{,}000 \times 125/100{,}000 \doteq 43.8$ kilowatt-hours.

3. The rate of increase in temperature should not exceed about 7 degrees F per hour; 125 degrees F rise will therefore require 18 hours; 43.8 kilowatt-hours divided by 18 equals 2.4 kilowatts required to increase the temperature of 10,000 pounds of steel 125 degrees F in 18 hours. This is based on the assumption that no heat is lost by radiation or by forced or natural convection. The kilowatt capacity thus calculated may be increased to some extent, say to 3.5 or 4 kilowatts, to allow for heat loss. If precautions are taken against heat loss and the fresh air admitted to the machine is limited, it may be possible to raise the temperature to 200 degrees F with less than 2.4 kilowatts but it will require more time to do it.

5–24. *Drying with Infrared Rays*

Equipment for producing heat by the use of infrared rays is now available in some shipyards. This is an effective method of drying insulation and is readily controlled. High surface temperatures are attainable with this method of heating, and precautions should be taken against overheating. There is no magic penetrating power of infrared-ray heating. It is merely an effective way of transmitting heat through space.

5–25. *Drying with Circulating Currents*

1. It is sometimes difficult to dry large machines satisfactorily by the use of external heating only. After removal of as much moisture as possible by this method, drying may be hastened by circulating current through the windings from an external, low-voltage current source. This should be provided with means for adjusting the voltage to limit the current through the windings. Exciter sets or low-voltage arc-welding sets are suitable sources of current. When the windings which are to be dried are of equal resistance and current-carrying capacity (such as the phase windings on the stators of a-c machines or the windings on field poles), they may be grouped in series or parallel depending upon which is best suited to the voltage available. A decision as to whether dc or ac is to be used should be based upon the following considerations:

a. Direct current should be used for the field windings of both a-c and d-c machines and for d-c armatures.

b. Either dc or ac may be used for the stator windings of a-c generators and motors except that ac should be used only when the rotor of the machine is removed. Otherwise the rotor may be heated excessively.

2. Circulating current from an external source may also be used for drying small machines. When there are a number of these of the same size and rating, their windings may be connected in series to suit the voltage available.

3. A generator which is in running condition can be dried without an external source of current by short-circuiting the stator phase windings or armature leads,

applying partial field, and driving the machine at reduced speed. The current should be carefully controlled by means of the field and speed in order to prevent overheating.

4. The following precautions should be observed when drying machines by circulating current:

a. Even though the voltage required for circulating current through windings is usually low, it is important that the winding be reasonably free from moisture before this drying method is employed. Current should not be circulated through any winding which has an insulation resistance of less than 50,000 ohms at room temperature.

b. Current should not be conducted into a d-c armature through brushes resting on a stationary commutator. This will cause localized heating of the commutator. The armature should be rotated continuously by some external means if it is necessary to dry by means of circulating current.

c. When drying by circulating current, the temperature must be increased slowly. Embedded temperature detectors or thermometers on the outside of the insulation will not indicate the hottest spot or copper temperatures. Temperatures measured by embedded detectors or by the hot resistance method should not exceed 195 F. Temperatures measured by thermometer should not exceed 170 F.

d. When using circulating current for drying a-c stators, it is important that the stator end windings be heated sufficiently to drive out the moisture. The end windings on large machines have a large radiating surface, and unless heating with circulating current is supplemented with external heating, the temperature of the end windings will be considerably less than the temperature of the embedded section of the coils and the result will be insufficient drying of the end windings. The use of external heaters to increase the temperature of the end windings will avoid this difficulty. In addition, on machines of 1,000 kilowatts or more, it is advisable to untape the end windings to facilitate escape of moisture.

5–26. *Insulation Resistance and Drying Progress*

1. The degree to which the properties of insulation are restored by drying may be determined to some extent by measuring the insulation resistance to ground. Readings should be taken when the drying is started, checked at regular intervals thereafter as long as the drying continues, and plotted on semilogarithmic paper with the logarithm of insulation resistance as ordinate and time as abscissa. The resistance-test record card (NavShips 531) provides a convenient form on which to do the plotting.

Figure 5–11 shows a typical drying curve as the insulation resistance usually drops owing to temperature effect as the machine warms up. This reaches a minimum when the winding reaches maximum temperature and then starts to rise rapidly at first then more slowly as the drying progresses. The observed insulation-resistance values may decrease slightly at times and then increase again at a slower rate as the moisture is driven out, indicating that drying is nearly complete. An erratic curve may indicate leakage paths to ground or weak insulation. Duplicate machines may show an entirely different response to drying. It must be remembered that two effects are present—drying, which increases insulation resistance, and increased temperature, which lowers insulation resistance. Temperature corrections as shown in Fig. 6–8 must be made to reduce the values to a common base.

2. The following methods can be used for measuring insulation resistance:

a. The preferred method is to use an insulation-resistance-measuring instrument (Sec. 6–12).

b. Another method is to use one or two 45-volt B batteries and a 150-volt high-resistance (at least 15,000 ohm) voltmeter of known internal resistance. If no B batteries are available, it is permissible to use a low-voltage (not more than 120-volt) d-c circuit provided a voltmeter test is first made to see if the circuit is grounded. See Sec. 6–21 for instructions on how to make this test and detailed instructions on how to measure insulation resistance by the voltmeter method.

3. As drying continues, the general trend of the insulation-resistance values indicates the progress in eliminating moisture. Drying should be continued until the insulation-resistance readings show no abrupt changes and do not increase more than 5 percent over a 12-hour period. The final value of insulation resistance for machine windings at the completion of drying should not be less than the minimum value given in Sec. 7–13, the value given in the "After cleaning in vessel" column applying if the machine is dried in place in the vessel and the value given in the "After reconditioning in shop" column applying if the machine is dried in a shop.

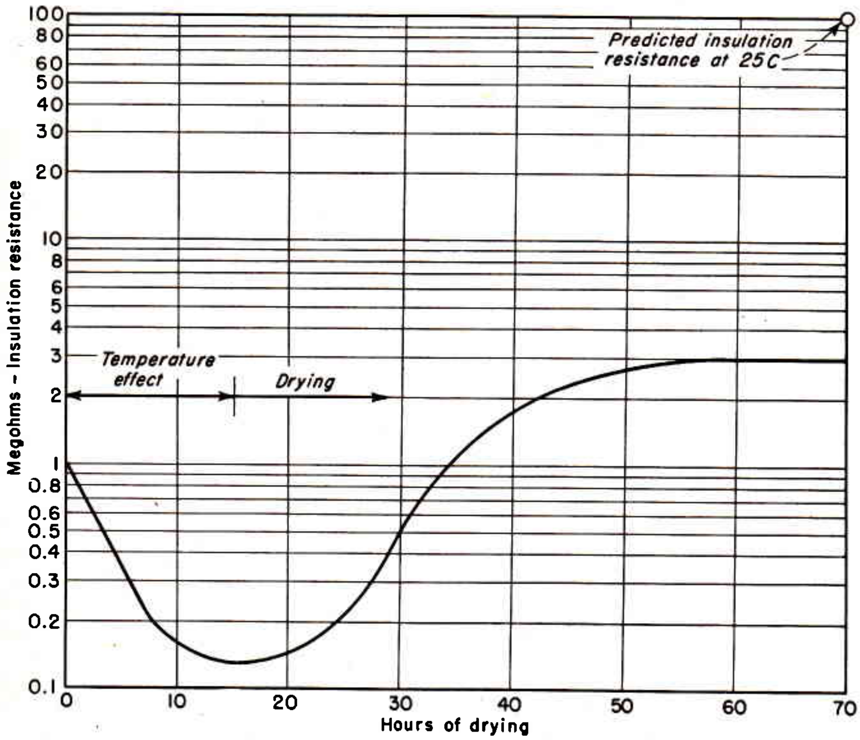


FIG. 5–11. Effect of drying on insulation resistance of a winding.

5–27. *Check on Completeness of Salt Removal*

The behavior of insulation resistance after drying can be used to furnish a check on the completeness of salt removal from equipment which has been splashed with or submerged in salt water. To make this check, measure the insulation resistance while the equipment is still hot from the drying proc-

ess and at frequent intervals as it cools to room temperature. Then allow the equipment to stand idle at room temperature for at least two days after the equipment is cold and preferably a longer period if time is available. The humidity should be high in the room where the equipment stands. Pans of water should be placed on heating coils if necessary. Measure the insulation resistance at frequent intervals. If feasible, let a machine which has not been subjected to salt water and reconditioned stand in the same room and compare its insulation resistance with that of the reconditioned machine. If the insulation resistance of the reconditioned machine falls rapidly when standing cold in a humid atmosphere, or if its insulation resistance is materially less than that of the other machine, the indications are that salt has not been completely removed and that the machine should be washed and dried again before proceeding with any further steps.

5–30. GENERAL INSTRUCTIONS ON REVARNISHING

The application of varnish will not permanently increase the insulation resistance or dielectric strength of insulating material and should not be used as a substitute for repairing or replacing defective insulation.

Varnish should never be applied to the whole or any part of a winding, by dipping, spraying, or brushing, until the winding has been thoroughly cleaned and dried. Varnishing a dirty or moist winding seals in dirt or moisture and makes future cleaning impossible.

Varnish should be applied only when it will serve a useful purpose. The unnecessary and frequent application of varnish ultimately results in building up a heavy coating which interferes with heat dissipation and is likely to develop surface cracks.

5–31. *Choice of Varnish*

It is generally recognized that the most satisfactory moisture-resistant coatings are obtained by dip-coating coils and apparatus in a suitable **baking varnish.** Spray coats are not equal in quality to those obtained by dipping. **Air-drying varnish films are less resistant to moisture than those obtainable with the better grades of baking varnish and are of lower dielectric strength.** Consequently, a baking varnish applied in accordance with Sec. 5–32 should be used whenever feasible. However, in many instances facilities are not available for baking electrical equipment. This is particularly true in the case of large and heavy generators and motors such as are used in some electric propulsion installations. In such instances, revarnishing should be done by spraying with an air-drying varnish in accordance with the instructions given in Sec. 5–36.

5–32. *Baking Varnish*

Insulation of electrical equipment is usually treated during manufacture with baking varnish of either the M or N type as listed in Navy Department Specification JAN–V–1137. The primary difference between these is that the M-type varnishes employ solvents which have a flash point below the value allowed for materials on Naval vessels afloat. While the M-type varnishes would be suitable for use by Naval activities ashore, it is considered desirable to standardize on the N type for Naval use because this may be used either afloat or ashore. The M- or N-type varnish used by the manufacturers may be either the clear baking (CB) or the black baking (BB) grade. **However, for reconditioning work by Naval activities it has been determined that the best adherence and most uniform**

results are obtained with the clear baking (CB) grade. Clear-baking (CB) N-type varnishes conforming to Navy Department Specification JAN-V-1137 are available from standard stock as Catalog of Navy Material Standard Stock No. 52-V-1300 in 1-gallon cans and 52-V-1305 in 5-gallon cans. When thinner is required for N-type varnish, it should be grade 1, Federal Specification TT-T-291, Catalog of Navy Material Standard Stock No. 52-T-725-5 (5-gallon cans) or 52-T-727-55 (55-gallon drums). See Sec. 5-1 through 5-5 for additional information on the subject of varnish-treatment procedures for new equipment.

In the past, some Naval activities have procured and used certain varnishes which are not compatible with the varnishes originally used on the equipment. In some instances considerable damage has been done to the equipment being reconditioned because of the chemical action of non-compatible varnishes. To avoid trouble of this kind, make sure that the baking varnish used is in accordance with this section and that it is applied in accordance with the instructions given in Sec. 5-34.

Silicone varnishes are semiorganic baking varnishes with high temperature stability and moisture resistance. They are now being used in building class H electrical equipment for shipboard applications and are available from standard stock for use by Naval activities engaged in reconditioning work.

The silicone varnishes can be handled in much the same way as the organic varnishes, such as grade CB of JAN-V-1137. There are certain precautions, however, that should be observed in the use of the silicone varnishes. Briefly these precautions are as follows:

1. Separate storage tanks should be provided. Silicone varnishes should not be mixed with any of the conventional organic varnishes, as they may react and precipitation may occur.
2. Separate dipping or impregnating tanks should be provided. Dipping tanks should have tight covers to prevent solvent evaporation.
3. There are no air-dry varnishes of the silicone-resin family suitable for treating electrical equipment.
4. Organic insulating components must be avoided in class H silicone equipment as their presence will result in destruction of the varnish film during baking or operation.
5. Silicone-insulated equipment should be prebaked before dipping to remove moisture from the winding and also to ensure that the silicone components are thoroughly cured to prevent any solvent softening. Prebaking at 300 to 400 F for 3 to 4 hours should be sufficient.
6. The viscosity of silicone varnishes should be maintained within the manufacturer's limits.
7. When thinner is required for silicone varnish, it should be xylene, Navy Department Specification 52-X-1, Catalog of Navy Material Standard Stock No. 52-X-1400-100 (50-gallon drums).

5-33. *Control of Varnish Drying*

The varnish for dipping and baking should be used in the dipping tank at a temperature of 25 to 32 C (77 to 90 F). Higher temperatures are undesirable, as baking varnishes increase in viscosity with age at elevated temperatures. For the same reason, baking varnishes should be stored in temperatures not exceeding 40 C (104 F).

The organic varnish should be maintained in the dip tanks at a viscosity of

50 to 100 seconds at 25 C as determined by the Zahn No. 2 (General Electric) or Demmler No. 1 (Westinghouse) viscosimeters. The silicone varnish should be maintained at a viscosity of 30 to 48 seconds at 25 C as determined by the Dow Corning cup No. 2 (see Sec. 5–5).

5–34. *Dipping and Baking Procedure*

After the equipment which is to be varnished has been thoroughly cleaned and baked, its insulation resistance has been measured and found to be satisfactory, and the equipment has cooled to room temperature, all rust-preventive compound applied to journals or other finished surfaces which will be immersed in the varnish should be thoroughly removed to prevent contamination of the varnish. The equipment should then be dipped in varnish and baked, as follows:

1. *Dipping.* The apparatus to be dipped must be at room temperature (see Sec. 5–2). The equipment should be immersed in varnish until bubbling ceases, at least 15 minutes for the first dip and 5 minutes for additional coats. If possible, a d-c armature should be dipped with the commutator end up and should be lowered in the tank until the commutator risers are barely covered. The commutator should be covered with kraft paper to protect it from the varnish. If an armature cannot be dipped with the commutator end up, the varnish should be placed in a pan and the armature lowered with its shaft in a horizontal position until the varnish covers the inside edge of the armature flanges. The armature is then slowly rotated until all parts are well covered and bubbling ceases. At least two complete revolutions should be made, each revolution taking about 10 minutes. During and after the second revolution, excess varnish should be removed from the external surface of the punchings and banding wire with an ordinary paintbrush. After dipping by the pan method, varnish should be heavily sprayed over all insulation and normally coated metal surfaces which have not been reached by dipping. This should include the back end of the commutator shell and V rings and all surfaces of the commutator risers. The front commutator V ring should be painted with varnish. The pan method of dipping may not be quite so satisfactory as the vertical dip in a deep tank and should be used only where a tank is not available and cannot be obtained.

2. *Draining.* After removing the apparatus from the varnish, drain until dripping ceases.

3. *Cleaning.* Any surfaces on which a build-up of varnish is undesirable, for instance, surface of armature, bore of stator, or pole faces, should be wiped with a rag moistened with thinner. This applies particularly when the apparatus is dipped and baked more than once. After the last dip, surfaces, with the exception of journals and metal-to-metal fits, should not be wiped, so that a protective film of varnish remains.

4. *Baking.* The apparatus should be baked in a forced-draft oven at a temperature shown in the following tabulation. The bake after each dip, except the last, may be 6 hours for organic varnishes JAN–V–1137. For the last dip in such varnishes and for **all** dips in silicone varnishes (HTB and LTB) bake for about 15 hours according to the table on page 140.

a. The time of the bake specified is general and may have to be modified depending on the size of the particular job. Small pieces of apparatus may be baked satisfactorily in somewhat less time than specified above, while very large pieces may require a longer bake.

Varnish grade	Baking-temperature range	
	Deg C	Deg F
CB or BB	130–135	266–275
HTB*	80–250	176–482
LTB*	80–200	176–392

* To prevent blistering, bake silicone varnishes at several steps at lower temperatures before the full temperature is applied: 3 hours each at 80 C, 150 C, and 200 C; 6 hours at 250 C. Follow varnish manufacturer's recommended curing schedule for best results.

b. The kind of oven and rate of air circulation have a very important bearing on the baking time. It may require several times as long to raise a piece of apparatus to baking temperature in one oven as it does in another of a different type.

c. Allowance should be made for loss of heat due to opening oven doors, failure of heat supply, or any other conditions which interrupt continuous heating at the specified temperatures.

d. It is preferable to bake armatures in a vertical position, commutator end up, if construction and oven facilities permit.

5–35. *Air-drying Varnish*

When it is necessary to use an air-drying instead of a dipping and baking varnish (see Sec. 5–32), it should be a clear air-drying varnish (grade CA) which conforms to Navy Department Specification JAN–V–1137. It can be obtained as Catalog of Navy Material Standard Stock No. 52–V–1255 (1-gallon can) or 52–V–1260 (5-gallon can). The thinner to be used with the air-drying varnish is the same as the thinner for type N baking varnishes (Sec. 5–32).

5–36. *Spraying and Drying*

Air-drying varnish should be used when varnish is to be applied by spraying. After the equipment to be varnished has been thoroughly cleaned and dried, the varnish should be applied in accordance with the following instructions.

Viscosity. Varnish for spraying should have a viscosity of 25 to 60 seconds at 25 C when measured by the No. 2 Zahn cup, No. 1 Demmler cup, or No. 4 Ford cup. When none of these cups is available, the viscosity can be measured approximately by the method described in Sec. 5–5. The viscosity of varnish as measured in this way should be about 3.5 to 9 times the viscosity of fresh water at a temperature of 22 to 30 C (72 to 86 F). Varnish which is above the desired viscosity should be thinned by using the thinner specified in Sec. 5–32.

Temperature. Equipment to be sprayed must be within the temperature range of 20 to 35 C (68 to 95 F). Equipment outside this temperature range cannot be treated satisfactorily. The varnish should be the same temperature as the equipment which is being sprayed.

Spraying Equipment. An air cleaner should be installed in the air lines between the compressor and spray gun to remove oil and water from the line. An air regulator should also be installed to regulate the air pressure. Any standard spray gun and nozzle such as the DeVilbiss, Eclipse, Patsche, Binks, etc., may be used. The choice of equipment will be determined by which is available and the type with which the operators can do the most satisfactory job. Experience in use usually determines which type can be used to the best advantage.

Air Pressure. The pressure within the range of 20 to 70 pounds per square inch which gives the best results with the equipment employed is the air pressure which should be used. Practice tests should be made to select the air pressure and the

values of other factors which will result in the most satisfactory spray job.

Spraying Procedure. Before it is used, the varnish should be strained through several layers of cheesecloth to remove skin or dirt. When spraying, the spray gun should be held within 6 to 12 inches from the work at all times in order to obtain the best results. It is essential that a smooth surface with a thin uniform coat be obtained. This depends to a great extent upon the skill and the experience of the operator. The spray stroke should be made with a free arm motion, keeping the motion of the gun parallel to the surface of the work at all points in the stroke. Holding the arm still and arcing the gun by moving the wrists result in uneven application and overspray at the ends of the stroke. The rate of spraying depends upon the ability of the operator, viscosity of the varnish, and atomizing pressure. These factors should be so adjusted that a full coat is deposited which does not sag when dried. An overlap should be used so that the main or central part of the spray overlaps the lower one-third of the preceding stroke. The spray gun should be moved uniformly at a constant speed. The material and air pressures should be adjusted to give a spray pattern 5 to 7 inches in length.

Number of Coats. Two coats are usually adequate for satisfactory protection, and in any case, no more than three coats should be applied.

Drying. The drying time to be allowed for each of the coats depends upon the atmospheric conditions to a large extent. The first coat of a two-coat application should be allowed to dry until tack-free, but in no case need this time exceed 24 hours. The final coat should be allowed to dry at least twice the time required for the material to reach a tack-free condition. In instances where circumstances require it, accelerated drying is permissible, but in no case should the temperature of the work be allowed to exceed 70 C.

Precautions. Other precautions to be observed when spraying equipment are as follows:

a. Spraying should not be done near open flames, heaters, etc.

b. Adequate ventilation must be provided.

c. The operator should wear a respirator and goggles.

d. Spray guns must be kept clean and in good condition. The instructions provided by the manufacturer should be followed.

e. Do not spray at low temperatures (below 20 C) or with the work at low temperatures.

f. Avoid the application of heavy films.

5–37. *Application of Varnish by Brushing*

Application of air-drying varnish by brushing should be limited to reaching places that cannot be reached satisfactorily by spraying but that can be reached by a brush, to touching up small spots which are of too limited area to warrant spraying, or to the application of varnish to isolated parts of a complete equipment where spraying might get varnish on parts where it is not desired.

5–40. RECONDITIONING ELECTRICAL INSULATION DAMAGED BY SEA WATER

Electrical equipment may be damaged by being submerged in or by being splashed with sea water. Since reliability is imperative in electrical equipment, such equipment should be restored as nearly as possible to new-machine condition. Much experience has been accumulated on reconditioning electrical equipment that has been damaged by sea water. **This experience shows**

conclusively that the work must be done thoroughly in order to minimize the possibility of subsequent failure.

The equipment should be immediately dismantled if possible to permit cleaning and rust-preventive treatment of the component parts. Where disassembly is not practicable, the treatment should be as thorough as possible. If fresh water is available, the equipment should first be washed either by the use of a hose or by submersion. This will remove a certain amount of salt water. After washing or when fresh water is not available, all accessible parts should be wiped dry. All water should be removed as thoroughly as possible from the bearings of rotating machines and other spaces where it may be entrapped. If available, compressed air may be used as an aid in drying. When applied to insulation which is to be reconditioned, the air pressure should be limited to a value which will not mechanically damage the insulation. A pressure of 25 to 50 pounds per square inch will usually be satisfactory, but this will depend upon the type and condition of the insulation. The compressed air should be free from abrasive particles which may damage insulation.

5–41. *Preliminary Cleaning*

After disassembly for inspection and determination of the measures to be employed in reconditioning, cleaning operations should be initiated on equipment which has been subjected to fuel or lubricating oil, contaminated water, etc. In order to facilitate the cleaning, disassembly should be as complete as possible and parts which are to be replaced should be removed. Numerous materials and solvents are available for removing grease, oil, and other foreign deposits, but it is important that the properties, characteristics, and limitations of each be known. Certain solvents readily remove grease and oil but may injure varnish and impregnating compounds. Others are inflammable and explosive under certain conditions or may produce toxic effects on persons exposed to the fumes.

5–42. *Cleaning by Means of Compounds and Water*

The following compounds are standard Navy stock items and may be used for cleaning electrical equipment which has been submerged.

1. Compound cleaning, as covered by the latest issue of Federal Specification P–C–431 (Catalog of Navy Material Standard Stock No. 51–C–1569), should be mixed in a proportion of 1 pound to 2½ gallons of water and can be used on insulation which is to be reconditioned. After the cleaning is completed, all surfaces should be thoroughly washed with fresh water to remove the alkali.

2. Powdered salt-water soap (synthetic detergent), as covered by the latest issue of Navy Specification 51–S–47 (Catalog of Navy Material Standard Stock No. 25–S–35140), may be used in soft or hard water and should be mixed in a proportion of 1 pound to 50 gallons of water. This compound has the advantage of being neutral; *i.e.*, it is neither acid nor alkaline, and can be used to clean insulation which is to be reconditioned.

3. Dishwashing compound, as covered by the latest issue of Navy Specification 51–C–49 (Catalog of Navy Material Standard Stock No. 51–C–1576–15), should be mixed in a proportion of 1 pound to 25 gallons of water. This solution may be injurious to the skin, and proper precautions such as the use of rubber gloves should be taken. All traces of alkali should be re-

moved with fresh water after the cleaning has been completed. This cleaning solution should not be used on insulation which is to be reconditioned.

5–43. *Cleaning by Means of Solvents*

The choice of a solvent will depend upon the availability, the degree of fire risk involved, and the facilities for maintaining adequate ventilation. Gasoline or benzine should not be used for cleaning purposes under any circumstances. The principal solvents approved for use in removing oil, grease, etc., are as follows:

1. Carbon tetrachloride as covered by the latest issue of Federal Specification 0–C–141 (Catalog of Navy Material Standard Stock Nos. 51–C–775 or 51–C–785).

a. This is a chlorinated solvent which is nonexplosive and noninflammable, but it may produce severe toxic effects. Carbon tetrachloride vapor is heavier than air and will accumulate in confined spaces, resulting in suffocation if adequate ventilation is not provided. An exhaust fan with its suction under the apparatus being cleaned and discharging into the outside atmosphere will provide the most reliable means of protection to the operators.

b. The vapor of carbon tetrachloride may be especially toxic to persons addicted to the use of alcohol. When engaged in cleaning operations with this solvent, the consumption of alcohol should be forbidden even outside working hours.

c. Calcium and glucose serve as protective elements against the toxic effects of carbon tetrachloride. Operators should be encouraged to drink plenty of milk and eat sweets during the time they are engaged in such work. Personnel should be warned to get away from the fumes as soon as any signs of dizziness, nausea, headache, extreme fatigue, etc., are experienced.

d. Carbon tetrachloride may be irritating to the skin, since it tends to remove the oil and leave the skin dry and white. The use of rubber gloves is recommended if the hands are to be subjected to this solvent. In case of skin irritation, the condition may be alleviated by the application of animal or vegetable oil.

e. Carbon tetrachloride is very corrosive, and if allowed to collect in pockets where it does not evaporate readily, it may prove injurious to certain varnishes and insulation. Before using, observe the action on a small area or sample of the insulating material. If it is apparent that it will injure the varnish or insulation, another solvent should be selected.

f. Carbon tetrachloride will cause rusting on bare ferrous surfaces, and if it inadvertently comes in contact with such surfaces, it should be completely removed. It must not be permitted to come in contact with a commutator, either on the copper or on the segmental mica insulation between bars. Unsatisfactory brush operation may result if the brushes are subjected to carbon tetrachloride.

2. Trichlorethylene, as covered by the latest issue of Federal Specification 0–T–634 (Catalog of Navy Material Standard Stock Nos. 51–T–5751 and 51–T–5758), is another chlorinated solvent which has properties similar to those of carbon tetrachloride. It is widely used in a vapor process for degreasing metals. In general, the same safety precautions apply to the use of this solvent as for carbon tetrachloride. The effect on varnish or insulation should be tested before general application.

3. Dry-cleaning solvent (Stoddard solution), as covered by the latest issue of Federal Specification P–S–661 (Catalog of Navy

Material Standard Stock Nos. 51–C–1326–67 and 51–C–1326–75), is a safety-type solvent in which the fire and health hazards have been minimized. Nevertheless precautions against fire and explosion should be observed. The efficiency of this solvent will be somewhat less than that of the chlorinated solvents, but ill effects to personnel will also be reduced. Experience has shown that this solution has an injurious effect upon some types of insulation. Before using it, a test should be made by applying the solution to a small spot on the insulation concerned to determine whether it is affected by the solvent.

4. Thinner, paint, and petroleum spirits, as covered by the latest issue of Federal Specification TT–T–291 (Catalog of Navy Material Standard Stock Nos. 52–T–725–5, 52–T–725–55, and 52–T–725–100). Grade 1 of this material may be used as a solvent for grease or oil removal.

5–44. *Precautions*

During the use of any solvent the following rules should be observed:

1. Guard carefully against fire.
2. Use vaporproof or watertight portable lights if supplementary lighting is required.
3. Have fire extinguishers available for immediate use.
4. Prevent possible sparks caused by one metallic object striking another.
5. If a spray or atomizer is used, ground the nozzle.
6. Avoid saturation of the operator's clothing with the solvent.
7. Provide liberal ventilation by means of exhaust fans or other suitable means.
8. When using carbon tetrachloride or trichlorethylene, protection against breathing the fumes must be provided and the operators should be under the observation of someone familiar with artificial respiration.
9. If the cleaning must be done in a space which lacks adequate ventilation, gas masks or preferably fresh air supplied from outside the enclosure should be provided. When carbon tetrachloride or trichlorethylene is used, a gas mask will not prevent suffocation, since the vapor from these solvents displaces air and oxygen.
10. No less than two persons should be assigned to cleaning operations in a single compartment.

5–45. *Application of Cleaning Solvents*

Solvents should be used for routine cleaning to the minimum extent practicable. When used for cleaning equipment that is to be reconditioned, solvents may be applied by means of lintless cloths moistened with the fluid, by spraying, or by immersion of the parts in the solvent. Judgment must be exercised as to how much of the solvent is applied depending upon its corrosive action. Where extremely volatile solvents are applied by means of a spray, the nozzle should be held sufficiently close to the work to ensure that the vapors reach the surfaces being cleaned. Obstinate foreign materials may be removed with a scraper or scrubbed off with a brush. After the apparatus is cleaned, it should be dried thoroughly by wiping and applying compressed air until all traces of the solvent have been removed. If compressed air is applied to insulation consisting of tape and it is to be reconditioned, the air pressure should not exceed 50 pounds per square inch and the air should be free of abrasive particles.

5–46. *Removal of Salt*

1. The principal salt found in sea water is sodium chloride. In addition, magne-

sium chloride and calcium chloride are present in lesser amounts. Since these salts have a corrosive effect on metals, it is important that all traces of sea water and salt deposits be thoroughly removed before restoring the equipment to service. If not removed, salt deposits will absorb water and cause continued corrosion and hazard of insulation failure. This may eventually result in failure of rotating parts such as the teeth on core laminations of rotors, or if the corrosion occurs in proximity to insulation, deterioration and insulation failure may occur. It is very important that salts be thoroughly removed as soon as possible to prevent damage from corrosion.

2. After disassembling as completely as possible, the parts should be thoroughly washed with fresh water. In certain localities, supposedly fresh water may be brackish, and unless it is known that the salt content is insignificant, the water used for washing should be given a salinity test. Where the salt content is appreciable, provision must be made for removing the salt or the equipment must be moved to a point where fresh water is available to complete the washing operation. The temperature of the water has little effect on the solubility of the salts, but hot water will be more effective in removing oily or greasy deposits. If possible, the equipment should be immersed in fresh water which is constantly being changed by continuous flow and allowed to soak for several hours. Where a continuous flow of water is not available, the water should be changed frequently. If immersion is impracticable, as may be the case where large machines are involved, the fresh water may be applied with a hose. Care must be taken to avoid damage to insulation which is not being renewed. Usually no insulation damage results if the water pressure does not exceed 25 pounds per square inch.

3. As the washing progresses, drippings from the equipment should be tested for salt content. This may be done with a standard salinity test set carried aboard ship for determining the salt content of boiler feed water. Washing should be continued for at least one hour after the salinity tests show that the salt has been removed. This may require several hours or even days of washing, depending upon the size and construction of the equipment.

4. In addition to the salinity test, equipment which has been exposed to salt water should be tested for insulation resistance after drying to obtain another check on the completeness of salt removal, in accordance with Sec. 5–27.

5–50. TREATMENT OF APPARATUS FOR OPERATION IN TROPICAL CLIMATES

It has been found that apparatus which is operated in tropical climates encounters very severe conditions which may seriously affect the insulation characteristics. A great deal of experience was obtained by the armed services during World War II which led to basic investigations of the problems by a number of universities and various manufacturers as well as special laboratories of the United States government. The net result of all this investigation and experience by the armed services can be summed up in a few definite statements of fundamentals:

1. The growth of fungi, bacteria, and other minute organisms is generally associated with severe humidification of apparatus, which accelerates such growth.

2. The availability of a food supply is essential to the growth of such organisms.

3. Although it is possible to poison these organisms through the use of special varnishes containing poisons, this is not a permanent solution. The poisons are in-

effective unless they migrate toward the surface. Since the poisons are contained in thin varnish films, they are only temporarily effective. Furthermore, the migration of the poisons through the varnish film produces porosity, and therefore the varnish films cannot be relied upon for moisture protection.

4. The best solution to these problems is to employ insulating materials which the organisms cannot use for food. The inorganic insulating materials such as mica, glass, and asbestos are not food for these organisms. Furthermore, the man-made molecules of the synthetic resins are not food, as the organisms have not yet learned to assimilate them.

On this basis the use of class A insulation should be avoided, but class B and class H insulation will both be more satisfactory. It is desirable to use synthetic resin varnishes especially of the phenolic type. Alkyd varnishes are also satisfactory especially if they are pigmented, for example, with red iron oxide. In general it is advisable to avoid using oleoresinous varnishes, as their basic components occur in nature and are therefore readily adaptable for food by fungi, bacteria, and other minute organisms existing in tropical climates. Class H insulation employs synthetic silicone varnishes and inorganic insulation components. These are believed to be the most highly resistant available materials. **Class A insulation should not be used in tropical service because it is in general more moisture absorbent than other forms of insulation, is essentially cellulosic in nature, and employs natural resins and oils (food for fungi) for its treatment.**

Whenever severe moisture conditions are encountered such as in tropical service, it is customary to apply extra coats of surface treatment. Frequently four (or more) dips and bakes are given apparatus instead of two, which is customary for normal industrial service. In addition spray coats of air-drying varnish containing red iron oxide pigment give a pleasing finish and provide additional protection in tropical service.

Joint Army-Navy Specification JAN–T–152 describes a variety of fungusproofing compounds which are temporarily effective if properly applied and used within their known limitations. These are frequently applied for protection during shipment and storage prior to operation.

5–51. *Protection of Electrical Apparatus during Shipment and Storage*

Electrical apparatus presents special problems in protection during shipment and storage. The insulation and organic varnishes are both susceptible to moisture, which may upon prolonged exposure result in serious damage. It is therefore important that reasonable precautions be exercised during shipment and storage in order to protect these vital parts of the electrical apparatus. During World War II the armed services found that many of the current ideas concerning packaging and protecting apparatus were erroneous. Bitter experience taught that there are only two satisfactory methods of protecting the insulation of such equipment. The same methods apply to mechanical parts which are subject to corrosion. The only satisfactory methods of protection are:

1. Completely seal the part or machine within a moisture-vapor barrier, and include within this barrier a suitable desiccant for the absorption of excess humidity. Since all such vapor barriers do transmit a small

amount of water vapor, the quantity of desiccant must be sufficient to protect for the full period of storage.

2. Protect the apparatus from direct rain or snow, and allow adequate ventilating space in the enclosure so that natural convection currents are induced. All resinous films can tolerate saturated humidity conditions for intermittent periods provided that a recovery period is allowed thereafter.

Before the experience during the last war many had the mistaken idea that closely covering equipment with a tarpaulin or some other covering was a satisfactory means of protection against weather. This is positively the worst thing that can be done, as it generally results in making a "sweat box" out of the enclosure. In such enclosures there is always some moisture present, and surface condensation will result during temperature cycling. It is therefore imperative to provide adequate ventilation in equipment storage unless the apparatus is completely sealed and a suitable desiccant enclosed. Needless to say when such apparatus is sealed in a moisture-vapor barrier, packages should not be opened until ready to be used.

5–52. *Storage and Care of Coils and Insulating Materials*

Insulated coils and insulating materials must be handled with care and stored under favorable conditions if their full useful life is to be obtained. The practice of throwing these perishable spare parts carelessly into a bin or hanging coils on pegs in the nearest makeshift or available place should be avoided. Experience has shown that materials of this kind when exposed to dirt, moisture, or changing atmospheric conditions deteriorate much more rapidly than when properly stored, whether they are in service or not.

Storage Conditions. The ideal storeroom should have good ventilation with clean air that is not hot or dry or cold or damp. The specific engineering recommendations for ideal storage of coils and insulation are "store at 60 to 70 F with 40 to 50 percent relative humidity." Without air conditioning, these conditions could not be maintained. They will usually be approached sufficiently, however, in temperate climates by a room that is well ventilated in the humid summer months and heated in winter. The storeroom air must be sufficiently dry at all times that moisture never condenses on the walls or contents. This may be assured by maintaining the air 5 to 15 degrees F above the ambient temperature outside the room. Electric heat is preferred in obtaining this temperature rise in that there is no danger of moisture developing from burning gas or a leaky steam pipe. The arrangement of material within the storeroom should be orderly and systematic, so that coils and insulation receive a minimum amount of handling.

Untreated cloths and papers may be stored with sufficient wrapping to keep them clean and dry.

Varnished cloth and papers should be wrapped to prevent too free access of air. Careful wrapping with moistureproof paper and a dip in melted paraffin have been found adequate. Also storage in tightly closed tin containers has been found to be adequate. Careless storage of these materials may lead to their loss through spontaneous combustion, with consequent loss of other materials due to fire thus started.

Hard fibre and fish papers should not be stored too close to heating equipment or ovens where they are dried out too thor-

oughly, as such conditions will make them too brittle to work. These materials should be dried out after they are in position on the apparatus.

Flexible mica tape and wrapper material contain a volatile thinner and must be tightly sealed in tin containers to preserve them.

5–53. *Packing for Storage*

Coils and insulating materials, properly packed for shipment by the manufacturer, should be stored if possible in the original packages. Containers or wrappers should be plainly marked for identification of contents.

If coils are too large or there are too many to warrant packing, they may be stacked in rows and layers, using supported blocking between layers to relieve each of the lower layers from the weight of those above and carefully covered with tarpaulins on top only to protect from dust. Tarpaulins and stacking should permit free circulation of room air.

5–54. *Tropical and Other Severe Storage Conditions*

The foregoing recommendations are designed for good storage conditions in moderate climates or where equivalent conditions can be maintained in less favorable locations. In coastal, tropical, and some marine and industrial applications, humidity and related conditions, such as the presence of fungi and termites, make special precautions necessary. The armed services in handling and using equipment in all parts of the world have found that special packing and protection are necessary even for short-time storage in many of these locations. Elaborate packaging methods involving sealed wrappers and containers have been developed and are described in detail in many government publications. **Such packages must not be opened until the material is to be used.**

6. Testing Electrical Insulation, Coils, and Windings

Electrical testing of insulation and windings is a broad field, as many kinds of tests are employed. This discussion will be concerned primarily with testing of windings and the principles pertaining thereto. As an introduction several standard tests on materials will be reviewed briefly with extracts from ASTM standards which may aid in a better understanding of the broader subject.

6–1. DIELECTRIC STRENGTH OF ELECTRICAL INSULATING MATERIALS AT COMMERCIAL POWER FREQUENCIES*

The methods of test consist of procedures for the determination of dielectric strength of solid, semisolid, and liquid electrical insulating materials (except where a specific material requires a certain amount of special treatment).

The dielectric strength of an insulating material (maximum potential gradient that the material can withstand without rupture) is calculated from the observed breakdown voltage and the thickness of the specimen at or near the point of rupture and is commonly expressed in volts per mil. The value obtained in a test will depend upon the method and conditions of test. The dielectric strength of insulating materials decreases with time of exposure to the electrical stress. Tests involving short exposures are, therefore, primarily comparative and not indicative of the breakdown of the materials under prolonged exposure to lower stresses.

For quick determinations of dielectric strength, the short-time test is used. For fairly rapid determinations, but laying more emphasis upon the time factor, the step-by-step test is preferred. (For important details of standard dielectric tests on materials refer to ASTM D149.)

6–2. TEST PROCEDURE AND REPORTS

1. *Short-time Test.* The voltage is increased from zero to breakdown at a uniform rate. For solid materials, the rate of rise should be 0.5 or 1.0 kilovolt per second depending on the total test time required and the voltage-time characteristic of the material. For the rate applicable to a given material, reference should

* From ASTM D149.

be made to the test method for that material. For liquid materials, the rate of rise is usually 3 kilovolts per second.

2. *Step-by-step Test.* An initial voltage should be applied equal to 50 percent of the breakdown voltage in the short-time test, adjusted as shown in the following table:

Breakdown Voltage by Short-time Method	*Adjust 50 Percent of Breakdown Voltage to the Nearest*
25 kv or less	1.0 kv
Over 25 to 50 kv, incl.	2.0 kv
Over 50 to 100 kv, incl.	5.0 kv
Over 100 kv	10.0 kv

The voltage is then increased in equal increments as stated in the various material specifications, the voltage being held at each step for a definite time (usually 1 minute). The change from each step to the next higher should be made as rapidly as possible, and the time of change included in the succeeding test interval.

Usually five tests are made. If the average deviation from the mean exceeds 10 percent, or if the individual test deviates more than 15 percent from the mean, five additional tests should be made. The dielectric strength is determined from the average of all tests.

The test report should include:

The thickness of the specimen.

Total volts at each puncture.

Volts per mil for each puncture.

The average, maximum, and minimum volts per mil for each sample.

The temperature of the test specimen.

The percentage relative humidity of the surrounding air.

The conditioning treatment.

The duration of the test.

In the step-by-step test, the value of the initially applied voltage and the value of the voltage at each step.

The size and type of electrodes.

6-3. THERMAL CONDUCTIVITY TESTS ON ELECTRICAL INSULATING MATERIALS*

This test is intended for comparing the thermal conductivities of solid electrical insulating materials which are in the form of flat sheets. An accuracy of 10 percent can be obtained with this method. The thermal conductivity of a homogeneous material is defined as the rate of heat flow under steady conditions per unit area and per unit temperature gradient in the direction perpendicular to the area. Thermal conductivity is expressed in watts per unit area per degree C per unit thickness. (The units may be inches or centimeters.) The principle of the method is comparable to the potentiometer method of comparing electrical resistances. A specimen of unknown conductivity is placed in series with a reference standard of known conductivity between plates which are maintained at different temperatures. When a steady state of heat flow is attained, the temperature differences across the reference standard and the test specimen are measured and the conductivity of the test specimen is calculated from the following equation:

$$K = K_1 \frac{L}{L_1} \times \frac{\Delta t_1}{\Delta t}$$

where K = conductivity of the test specimen.

K_1 = conductivity of the reference standard.

L = thickness of the test specimen.

L_1 = thickness of the reference standard.

Δt = temperature difference across the test specimen.

Δt_1 = temperature difference across the reference standard.

* From ASTM D325.

6-4. INSULATION RESISTANCE OF ELECTRICAL INSULATING MATERIALS*

These methods cover the determination of insulation and volume resistance and approximate surface resistance of electrical insulating materials, also means of converting the last two into terms of volume and surface resistivities.

The volume resistivity is determined as the resistance between two electrodes which cover opposite faces of a centimeter or inch cube, provided the resistance of the surface layer is so high that it is not responsible for any appreciable part of the current.

The surface resistance between two electrodes is determined as the ratio of the voltage applied to the electrodes to the current which flows through the surface layers. Surface resistivity is four times the resistance between two electrodes covering opposite faces of a cube when the volume resistance is so high that practically all the current flows through the surface layers. This is equivalent to defining surface resistivity as the resistance between two opposite edges of a square of the surface layers.

Tests of the sort described by the ASTM are essentially for laboratory use, as complex systems of electrodes and guards are required. Those interested should refer to ASTM D257 for further details.

6-5. POWER-FACTOR TESTS

There are several methods of making insulation power-factor tests, and a number of different varieties of equipment are used. Since power factor is simply the ratio of the energy loss in a dielectric system (in watts) to the volt-ampere input, it is possible to make these measurements with a voltmeter, ammeter, and wattmeter. However, this involves very special varieties of meters because of the high sensitivity required. Power-factor tests are more frequently made with a bridge type of circuit. There are a number of these bridge circuits, but the more common ones employ capacitors and resistors which are manipulated to balance the dielectric characteristics of the specimen being tested. The values of the properties under observation are small and are affected by leakage and stray capacitance. Therefore, all types of power-factor testers require complex guard circuits in order to attain acceptable accuracy. For more complete information concerning power-factor tests on insulation refer to ASTM Standard D150.

Power factor is a convenient check of material uniformity. The change in power factor of insulation in service is sometimes used to observe deterioration due to moisture, foreign material, and mechanical damage and thus to anticipate failure. Its use has been extended to high-voltage bushings and oil. Experimental work is in progress using it for testing winding insulation. Considerable test data must be available on each type of material or assembly in order to interpret power-factor readings into condition of insulation. Power-factor tests should be considered as relative data rather than absolute yardsticks of quality or condition.

6-6. ARC-RESISTANCE TESTS

Tests of this nature are intended for determining the relative arc resistance of solid electrical insulating materials. In the ASTM arc-resistance test (D495) a high-voltage, low-current a-c arc is drawn between two tungsten electrodes resting upon the surface of the material under test. The energy input into the arc is increased

* From ASTM D257.

at 1-minute intervals until the material fails by becoming conducting. The time to failure is a measure of the arc resistance of the material. The standard voltage applied is 12,000 volts, 60 cycles.

There are other specialized tests for measuring arc resistance under other conditions. One high-energy arc-resistance test produces a 500-volt, 500-ampere d-c arc against the surface of the material to be tested. The duration of the time is controlled to 0.2 second. In this test the d-c voltage is reapplied to determine whether the surface has become conducting. Under this test the arc resistance is evaluated by the number of applications of the controlled arc that can be withstood before the surface becomes conducting.

6-7. OVERPOTENTIAL TESTING OF MACHINERY GROUND INSULATION

Since electrical apparatus was first constructed, it has been found desirable and economical, and in many cases absolutely essential, to prove the adequacy of insulation by overpotential tests. These tests begin while the material is in its preliminary form and continue through various stages of manufacture in the insulation, coils, and apparatus and during the operation of the apparatus throughout its useful life.

It is generally agreed that laboratory or factory tests cannot exactly simulate conditions of service or completely prove that insulation is suitable for operation in a specific service. In this connection, it must be recognized that insulation has many other important properties in addition to dielectric strength and that selection on the basis of initial dielectric breakdown strength alone does not necessarily produce the best design. The physical characteristics of the insulation and its thermal endurance determine how well its initial dielectric strength and other electrical characteristics are maintained throughout its life, because the ability of the insulation to withstand physical abuse is of utmost importance.

Sometimes overpotential tests are all grouped together in engineers' thinking, whereas they should be segregated into distinct classes according to their purpose. Tests are most generally made on insulation for the following reasons:

1. Tests to destruction are made on specimens of insulation or coils to determine the insulation level as a guide for engineers and inspectors in the selection, use, and quality control of various insulating materials. Similar tests are also made on samples during manufacture as quality-control checks.

2. Routine proof tests are made on insulation during manufacture to detect flaws. Generally these tests are momentary or short-time tests. Such tests not only are frequently made during the manufacture of the insulation but are also made during manufacture of the coils and the winding of the apparatus. Tests of this sort are primarily a matter of manufacturing economy to detect mechanical damage before repairs or replacements are costly. Therefore, it is important that such tests be sufficiently high to weed out serious defects and cases of damage in winding. In selecting the value for such tests, consideration should be given to both the inherent dielectric breakdown strength of the insulation and the spacing breakdown for the insulating wall thickness. Spacing breakdown voltage is the equivalent voltage at which air spacing will break down (see Sec. 1-16). The first proof test should be considerably below the expected dielectric breakdown of good insulation, and subsequent tests reduced in steps. Such proof tests are relatively useless in detecting flaws in solid

insulation unless their value is greater than the spacing breakdown for the insulation wall thickness. Preliminary momentary tests on coils and windings usually are the following values (percentages of final 1-minute test values).

Test Conditions	*Percentage of Final Winding Test Voltage*
Coil to ground:	
Before winding	150
First test after winding	125
Winding to ground, final test of winding before assembly	120

3. Acceptance tests are made to demonstrate that the insulation strength of the completed apparatus is above a certain specified level. The voltage values for such tests are established by industry standards (AIEE, ASA, and NEMA) and are intended to include suitable factors of safety, determined by experience, to ensure that the insulation will withstand:

a. Continuous application of rated voltage throughout the expected life of the machine.

b. Occasional overpotentials that frequently result from switching surges or some accident elsewhere on the system. Surges of 10 to 25 percent above line voltage are not uncommon, but they are of very short duration.

Usually standard apparatus acceptance tests are of 1-minute duration and are based on the formula:

$$E_t = M \times E + C$$

where E_t = test voltage.
E = rated voltage of the apparatus.
C = specified constant voltage.
M = multiplier for the particular application.

The curve of Fig. 6–1 plots test voltage as a function of rated voltage for general-purpose machines where C = 1,000 and M = 2. Certain special-purpose machinery may deviate from this.

4. Operation check tests are sometimes made periodically in service to ensure that the apparatus is in usable condition and that there are no incipient flaws in the insulation which might make it unsuitable for normal operation. Such tests must be made at test voltages well below the acceptance or factory tests for new apparatus, yet above the normal operating voltage. Sometimes unjustified reliance is placed on the mere fact that insulation has withstood a certain standardized overpotential test. Unless the test value and the spacing or creepage flashover voltage for the wall thickness are correlated, there can be no assurance of satisfactory operation. When clean and dry, some insulation with a complete puncture in the ground wall may withstand normal overpotential tests. However, it may fail in service later at normal operating voltage because of the accumulation of moisture and dirt in the puncture or crack in the ground wall or because movement of the winding opens up the damaged spot.

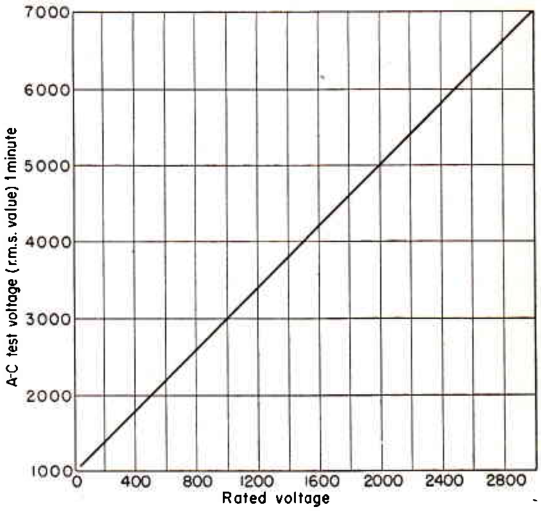


FIG. 6–1. Curve of standard AIEE overpotential test voltages.

Injury to insulation when produced by dielectric stress is dependent upon the time during which the stress is applied. There is a critical range in which stress is rapidly damaging. Stresses below this range may be applied for an indefinite period with relatively little damage to the insulation. As has been shown earlier in Chap. 1, an increase of 10 percent in voltage may reduce the time to failure by a factor of 10 to 1. The test voltage to be applied to an insulation to determine its suitability for operation is dependent upon many factors such as:

The nature and design of the apparatus.

Its operating voltage.

The nature of the service in which it is to be used.

The severity of the mechanical and electrical stresses to which it may be subjected in operation.

6-8. OVERPOTENTIAL TESTING PROCEDURE AND PRECAUTIONS

The objective of an overpotential test on a winding is to determine if insulation will withstand a known value of voltage successfully for a specific time. It is therefore of the utmost importance to control the conditions of the test so that unknown voltages do not exist on the winding. Failure to observe simple testing precautions can produce excessive voltages, up to double the intended voltage, which may easily destroy perfectly good insulation. The following precautions and procedures are recommended:

1. All windings not under test should be grounded. Unless grounded or connected to the circuit under test, such windings will reach an indeterminate potential, which on some occasions may actually exceed the test voltage on the winding being tested.

2. The test voltage should not be applied suddenly in a single step or surge voltages may be induced which are far above the intended voltage. Two types of voltage application are in general use for testing as follows:

a. Continuously variable control using an induction regulator or a variable transformer for adjusting the transformer primary voltage. The initial voltage should not be more than half the final test value but may be increased rapidly to the final test value.

b. Step-type control with switching to select voltage combinations (usually in the secondary). This type equipment must employ two-step voltage application to suppress surges which may occur when the test transformer is energized. This is usually accomplished by a resistance which is in series with the transformer primary. The first step of the control energizes the transformer primary through this resistor. A fraction of a second later this resistor is automatically shorted out. With such a test the desired voltage may be set on the selector switches and the full test voltage applied directly to the winding under test.

3. The test prongs connected to the winding under test and to ground must not be used to interrupt the circuit or this will

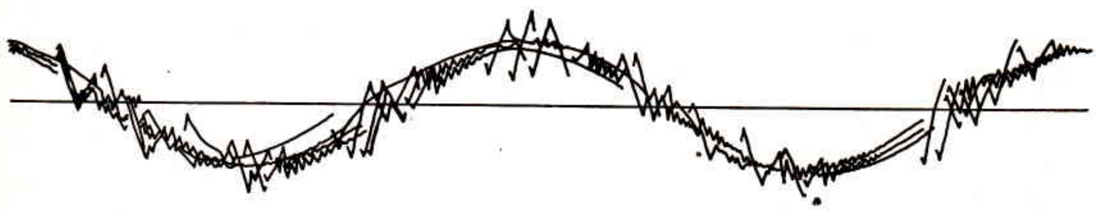


FIG. 6-2. Surge voltages induced by arcing test prongs. (*Westinghouse Electric Corp.*)

result in surges on the winding (see Fig. 6-2). It is desirable on important apparatus to fasten the test prongs solidly both to ground and to the terminals of the winding under test.

4. The test voltage should be applied for a specific time. The general practice is to test windings at a specific voltage for 1 minute. However, for special tests the value of the time may be varied. The time should always be checked carefully.

6-9. CALCULATION OF TEST TRANSFORMER REQUIREMENTS

When an a-c overpotential test is made, it is important that the test transformer be of ample size and capacity. If too small a transformer is used, there may be positive regulation (with a capacitance load) which produces a rise in the transformer output resulting in a higher test voltage than intended. For small and moderate-size machines, tested at lower voltages (16,000 volts and below), a 5-kilovolt-ampere transformer is adequate. However, if makeshift test equipment is used or a large winding tested, it is advisable to check the required testing transformer load before making the test.

$$\text{Charging kilovolt-amperes} = \frac{6.28 \times E^2 \times C \times f}{10^9}$$

where E = voltage (rms) at which test is made.
C = capacitance of winding to the frame, microfarads.
f = frequency of test voltage.

The capacitance of the winding under test can easily be measured with a capacitance bridge, if available. If such an instrument is not available, the capacitance can be approximated from the following formula:

$$C = \frac{0.448 \times K \times d \times L \times N}{t \times 10^6}$$

where C = capacitance, microfarads.
K = dielectric constant of the material (where mica is present K = approximately 5).
d = depth* of slot under wedge.
t = thickness* of insulation wall (copper to iron).
L = length* of core.
N = number of slots.

6-10. IMPULSE TESTS

Impulse tests (also called surge tests) are sometimes applied to windings to determine the ability of the insulation to withstand the line surges which are frequently superimposed on the line voltage. The impulse strength of insulation is usually defined with respect to the 1-minute, 60-cycle strength of the insulation and is stated as a ratio between the peak of the applied surge and the peak of the 60-cycle, 1-minute test which the insulation has withstood. No industry standards are available which define the surge strength of electrical insulation for rotating machinery. However, present-day thinking is that, if insulation has a surge-strength ratio of about 1.25, it is acceptable. Most conventional forms of insulation for rotating machines easily have this surge strength. AIEE Standards No. 4 (ASA C68.1) specifies conventional wave shapes and methods of measuring. It is customary to measure the crest value of surge voltages with a sphere spark gap or a cathode-ray oscilloscope (usually with resistance dividers). The wave applied is usually a rapidly rising steep-front wave which will reach crest in approximately 1 microsecond and will then decay more slowly. Impulse test waves are defined

* Dimensions in inches.

by two values. The first one specifies the length of the wave front; this is the time required for the voltage to rise from zero to crest. The second value is the time required for the voltage to decrease to half of the crest value. This is the tail. For example, a 1½ by 40-microsecond wave indicates that the time for the voltage to rise from zero to crest will be 1½ microseconds and that the time for the voltage on the tail to fall to half the crest value will be 40 microseconds.

Impulse tests have been established for most outdoor equipment to demonstrate the strength of insulation against the effects of lightning voltages. Voltage surges of specified wave shape and crest voltage are applied to specialized equipment only. The required tests and recording equipment are complicated and costly. As a result impulse tests have generally been restricted to equipment which is directly connected to overhead transmission lines. The primary exception to this is the routine impulse waves for short-circuit detection. This method is very useful for detecting winding faults and unsymmetrical conditions in the windings.

Considerable study of the winding inductance and capacitance is required before a high-voltage surge overpotential test can be applied to the ground insulation of electric machines. Unless these constants are known and evaluated with respect to the wave front of the surge test, it is possible to concentrate the surge voltage on part of the winding, which may result in damage to the insulation.

6–11. TURN–INSULATION TESTING

Cotton, asbestos, and glass wire covering is intended to provide positive separation between conductors. This should result in a breakdown voltage corresponding approximately to the spacing breakdown values given in the curve of Fig. 1–5. Varnish treatment of the wire may frequently result in increasing the breakdown level above the equivalent spacing breakdown level; however, it should not be relied upon to do so. On the other hand, mica-taped conductors having overlapping insulating barriers (flakes) can be expected to have a higher insulation breakdown level than other forms of conductor insulation. Likewise enameled conductors may have high breakdown strength due to the barrier effect of the enamel coating.

It is generally customary to test armature coils before winding and connection when it is possible to make a conventional overpotential test. Typical insulation testing practice between conductors is tabulated below.

Once a machine is wound and connected, the testing of turn insulation, to detect and locate faults (such as shorted turns), is much more difficult.

The "growler" is one of the oldest types of tester for detecting and locating the exist-

Turn-insulation Tests on Coils—Test Voltage, 60-cycle Rms

Apparatus	Mica tape	Asbestos	Glass	Double cotton covered
Integral horsepower motors.......	600	300	600	600
Large a-c and d-c motors and generators........................	1,000*	600	600	600

* Higher voltages are used for more than one layer of mica tape per conductor.

ence of faults in connected armature windings. It consists of a large a-c magnet, and the armature under test completes the magnetic circuit with its coils acting as secondary windings. The core may be a fixed size where identical armatures are tested, or it may be hinged when a wide variety of armature sizes will be tested. When power is applied to the winding of the magnet, the flux passes through the armature core, generating voltage in the armature coils. Shorted coils are detected by shorting adjacent commutator bars. If the coils between the shorted bars are in good condition, there will be vigorous sparking as the short is opened on the commutator bars. The absence of sparking indicates that the coil connected to the particular commutator bars either is short-circuited or has an open circuit. A short circuit can be readily detected by running a light piece of magnetic material over the periphery of the armature, bridging the slots in succession. If there is a short circuit in one of the coils, a current will pass through that coil producing magnetic flux which attracts the magnetic test piece at the slot carrying the shorted coil. No magnetic attraction over a coil and no spark between the commutator bars to which the coil is connected indicate an open circuit. Only coils within the range of core flux can be tested. It is therefore necessary to disconnect power from the growler coil and rotate the armature so as to bring each armature coil successively into the flux path. Similar growler-type testers can be used to locate defects in the stators of a-c machines. The pole pieces must be of suitable shape properly to contact the inner bore of the punchings. The usual method employed is to test opposite sides of the coils embraced between jaws with a magnetic test piece. This magnetic test piece will be attracted over slots containing a short-circuited coil. Where a short circuit exists, the magnetic test piece usually vibrates noisily. Another variation of the internal growler includes a vibrating reed between the tester poles which vibrates as the reed passes over the slot containing a short-circuited coil.

Although the growler is still in use and is a valuable shop tool, high-frequency or surge tests are gaining in popularity. Surge or high-frequency methods usually permit the application of relatively high turn-to-turn voltages and employ sensitive fault-detection means. High-frequency or surge tests are used because they set up a high impedance. The a-c impedance of a winding is essentially proportional to the frequency. This permits application of a high potential to the winding circuit without an excessive current through the winding. In these tests the total test voltage applied to the winding is distributed in a relatively uniform manner across the turns between terminals. This results in a voltage test between adjacent turns or coils of several times normal voltage, but with low current flow through the winding. Such tests have been proved to be satisfactory for weeding out incipient faults before they can cause service interruption. There are several types of apparatus which may be used for testing of turn insulation.

An early type of high-frequency-test outfit shown in Fig. 6–3 produces an oscillatory high-frequency discharge through a spark gap. This employs a high-voltage transformer charging a condenser which discharges through a rotating-disk air gap as shown in the diagram of Fig. 6–4. The oscillatory discharge thus produced is damped high frequency at the natural resonant frequency of the circuit. The condenser is charged repeatedly, and a series of these oscillatory discharges takes place in each

half cycle of the transformer power supply. The voltage of the high-frequency test is controlled by varying the air gap between the rotary disks. A wave meter is used for

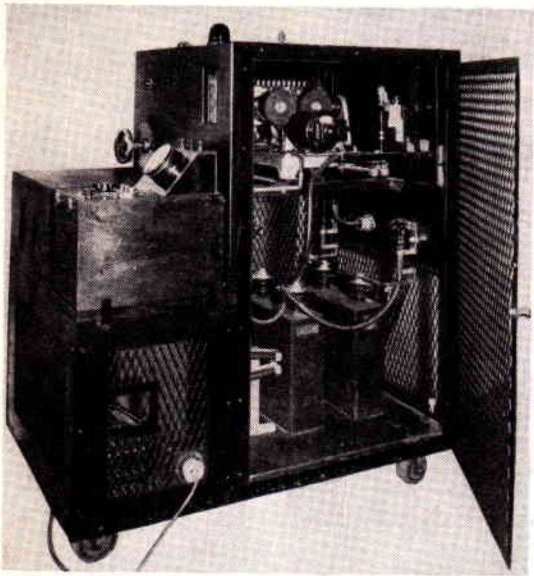


FIG. 6-3. High-frequency-test set. (*Westinghouse Electric Corp.*)

detecting insulation faults. Any short circuit in the winding changes the inductance and thereby the natural resonant frequency of the circuit, making this device very sensitive. For proper and consistent results

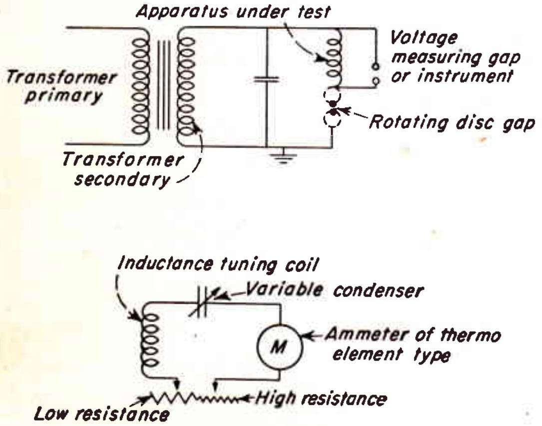


FIG. 6-4. Diagram of spark-gap high-frequency-test set. (*Westinghouse Electric Corp.*)

this device requires technically trained personnel to adjust and operate the test apparatus, as well as to interpret the results. This test permits the application of high turn-to-turn voltages.

More recently electronic-type oscillators have been employed as a source of high-frequency voltage for testing turn insulation and detecting short circuits in windings. Testers of this type supply a variable voltage at a controlled frequency. Usually the high-frequency voltage is measured by means of a cathode-ray oscillograph. Defects are detected by distortion of wave shape and by changes in amplitude of the wave where changes in circuit constants (due to faults) are sufficient to throw the circuit out of resonance. This test equipment provides a satisfactory source of high-frequency voltage for testing turn insulation and can be operated by testers with only a little training. However, on some apparatus, it is not so sensitive as other types of short-circuit testers, and frequently certain kinds of faults are hard to detect. It is particularly useful in testing a large number of similar units on a production-line basis. Usually intermediate turn-to-turn voltages are employed with this test.

Another form of high-frequency tester has been developed recently for d-c armature testing and is shown in Fig. 6-5. This employs a 3,000-cycle oscillator with a vacuum-tube voltmeter and cathode-ray, "magic-eye" indicator. A pair of test electrodes applies about 15-volt 3,000-cycle ac across several commutator bars. An inner pair of electrodes is connected across two adjacent bars to pick up the resultant voltage across a single coil. This tester is able to detect short circuits in coils or between commutator bars. The turn-to-turn test voltage applied by this test is low.

A recently developed insulation-test equipment, shown in Fig. 6–6, is suitable for testing turn insulation, similar to high-frequency tests, by applying surge voltages alternately in reverse directions through the winding. It also can be used for testing ground insulation. The equipment consists of a surge generator which is alternately connected to two winding terminals every other half cycle (of the 60-cycle power supply) by a synchronous double-throw two-pole switch. A simplified circuit is shown in Fig. 6–7. Thus surges are propagated through the winding first in one direction and then in the other. Their effect is observed on a cathode-ray oscilloscope so that the voltages across two parts of the winding (or two identical coils) can be compared. When the two windings are symmetrical, the images in the cathode-ray oscilloscope are identical and appear as a single image. Any fault, such as a shorted turn, affects the two waves differently and produces two images on the oscilloscope. The shape of the waves can be interpreted (from experience) as indicating the nature of the fault. It should be recognized that this device gives comparative information regarding two parts of a winding or two coils while applying a surge voltage to the winding.

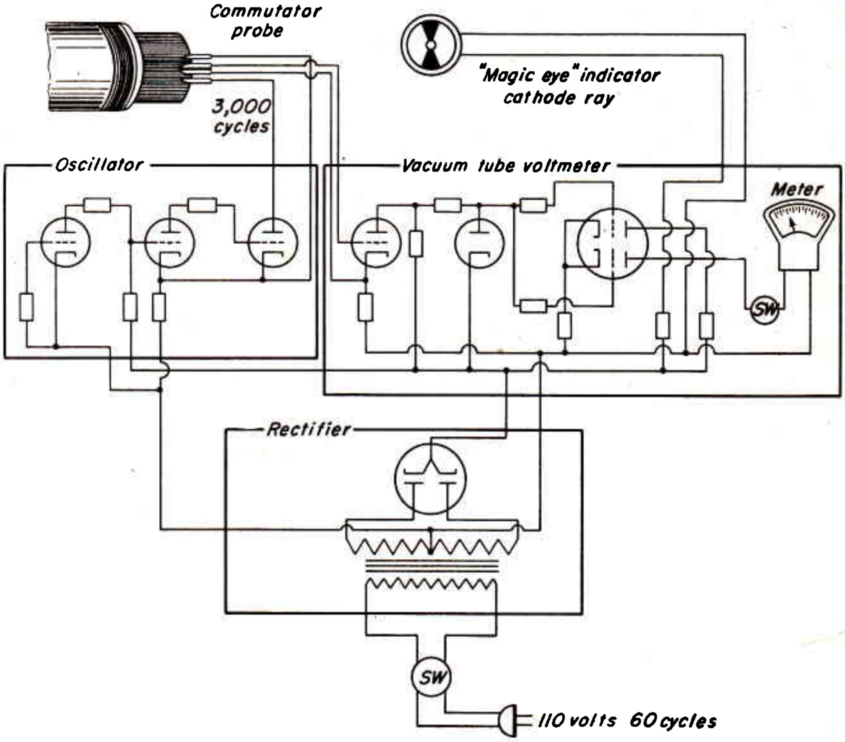


FIG. 6–5. Electronic portable bar-to-bar armature tester. (*National Electric Coil Co.*)

Normal testing technique with high-frequency and surge test sets is to apply the same test voltage across the complete winding that is applied between the winding and ground as a final overpotential test.

6–12. INSULATION-RESISTANCE TESTING IN ROTATING ELECTRIC MACHINERY

The insulation resistance of the windings on a piece of rotating electric machinery is affected by the construction of the machine,

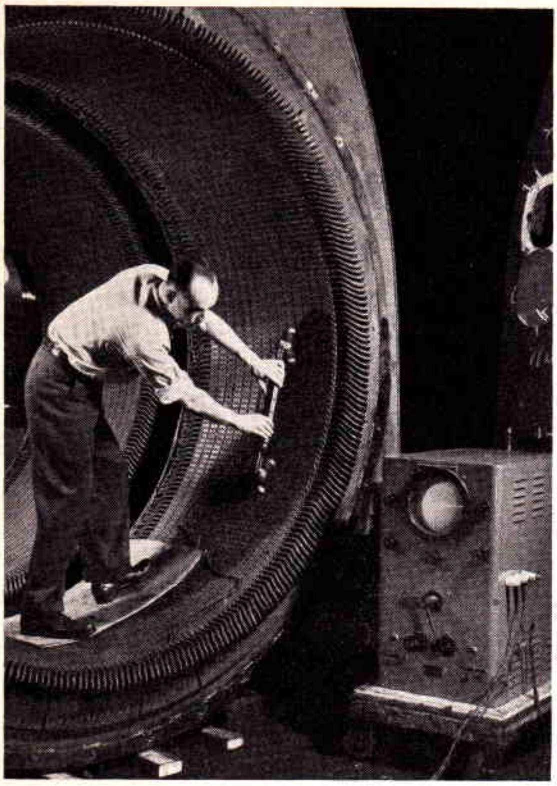


FIG. 6-6. Surge comparison test set in use on 3,300-hp troopship propulsion motor. (*Westinghouse Electric Corp.*)

moisture, temperature, cleanliness, and age and condition of the windings.

1. *Construction.* Dimensions, shape, number of turns, type of insulation, and process of manufacture all influence the insulation resistance of a winding. Windings in large or low-voltage machines will have inherently lower insulation resistance than those in small or high-voltage machines. Field windings will have inherently higher values than d-c armature windings or a-c phase windings. Under equivalent conditions d-c armature windings will have lower insulation resistance than phase windings of a-c machines of equivalent capacities owing to the numerous creepage paths at the commutator connections. The insulation resistance of class A insulation is inherently lower than that of class B insulation. The types of bonding and coating varnishes and the drying processes used also have considerable influence. Duplicate machines constructed in the same shop will differ in their insulation resistance because of the variations that occur in their manufacture.

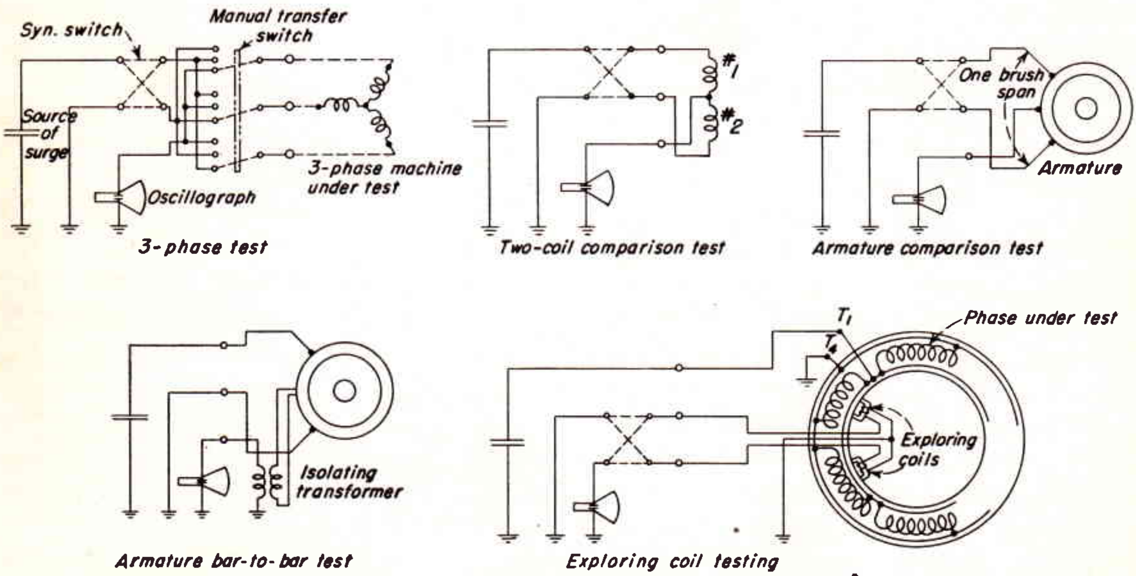


FIG. 6-7. Diagram of surge comparison test set. (*Westinghouse Electric Corp.*)

2. *Moisture*. *a*. When insulation stands in a moist atmosphere, it absorbs moisture and its insulation resistance decreases. The amount of moisture absorption is increased by increased time of exposure or by an increase in the relative humidity of the atmosphere. It also depends upon the type of insulation and its condition. Cotton, paper, and asbestos insulation materials absorb moisture more readily than mica. Vacuum-pressure impregnated windings usually seal out moisture more effectively than built-up or immersion-impregnated windings. Insulation that has cracked or is otherwise damaged usually is more susceptible to moisture absorption.

b. Since moisture may be driven off or evaporated by the application of heat, the insulation resistance of a winding having a low resistance due to the presence of moisture may be restored by energizing or externally heating the winding. However, if in addition to the moisture the insulation has deteriorated from exposure to oil, acid, or other harmful matter, the insulation resistance probably cannot be restored to its original value.

3. *Temperature*. *a*. As in the case of cables the insulation resistance of the windings on rotating electric machinery decreases as the temperature of the insulation increases. Insulation-resistance measurements taken at intervals can be properly compared only when taken at approximately the same temperature or when due allowance is made for difference in temperature.

b. Periodic measurements made at normal operating temperature, *i.e.*, immediately after shutdown, will furnish a series of measurements at approximately the same temperature.

c. When insulation-resistance measurements are made at different temperatures, allowance for the difference in temperature can be made by correcting all insulation-resistance values to what they would be if made at a standard temperature, 25 C (77 F) for example. This correction can be easily made by using the alignment chart in Fig. 6–8. To do this, find the measured value of insulation resistance on the left-hand scale and the temperature at which the resistance was measured on the right-hand scale. Pass a straight line between these points. The place where this line cuts the middle scale gives the insulation resistance corrected to 25 C (77 F). Figure 6–8 is based upon an average correction factor and gives results which are only approximate, but of sufficient accuracy for most purposes such as to correct insulation-resistance measurements made at any temperature to a base of 25 C so that they can be compared with the standards of insulation-resistance values.

4. *Cleanliness*. A winding in good condition in all other respects may have a low insulation resistance due solely to deposits of foreign matter, and the insulation resistance may increase to an acceptable value after a thorough cleaning. Machines operating in dusty or dirty atmospheres accumulate foreign deposits on their windings rapidly. Armature windings in d-c machines are more affected by foreign deposits than armature windings in a-c machines because of the exposed copper at the commutator. D-c machines are also more exposed to carbon and copper deposits from the brushes and commutator, particularly machines having closed ventilating systems. Consequently, the type and construction of a machine and operating conditions influence the rate at which foreign matter is deposited on the windings and the frequency with which a machine must be cleaned.

5. *Condition of Insulation*. *a*. Insulating materials deteriorate with age because of the

individual or combined effects of heat, moisture, vibration, mechanical injuries, dust, oxidation, and chemical action as from acid or alkali fumes, salt, air, or oil. The rate of deterioration depends upon the conditions to which the equipment is exposed and under which it operates, such as location, type of service, load, atmosphere, and amount of care. Even with the best of care, oxidation and corrosion may continue and cause deterioration, particularly if the machine is standing idle. The insulation resistance decreases as the insulation deteriorates, other factors assumed constant. For this reason, a comparison of insulation-resistance values over a period of time is of assistance in ascertaining the condition of the insulation and its suitability for service.

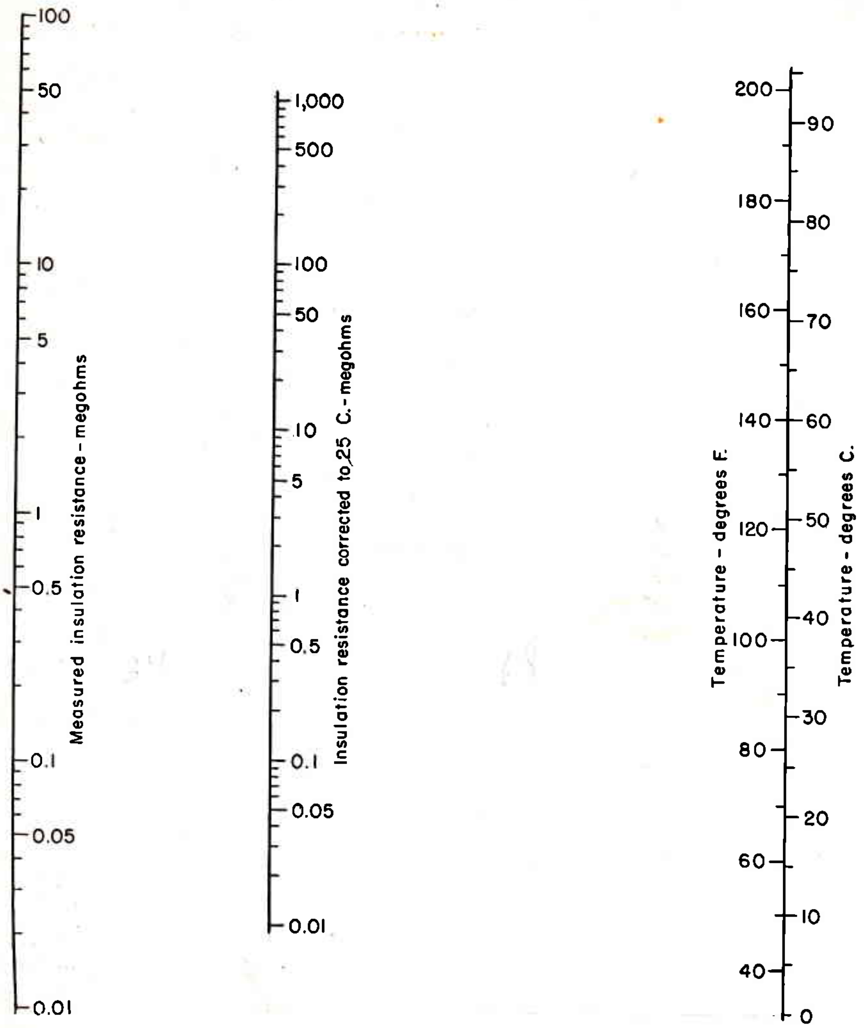


FIG. 6–8. Nomograph for temperature correction of insulation resistance.

b. Low insulation-resistance values are not always a positive indication of poor insulation even when the insulation is dry and clean. A new, or "green," winding may have a low insulation resistance due to the presence of the solvent used in bonding

varnishes. When the machine is placed in service, the solvent gradually evaporates and the insulation resistance tends to rise as the varnish dries. On the other hand, a high value of insulation resistance does not necessarily indicate that the insulation is in perfect condition. Thus, if the insulation has become brittle or has developed cracks, or if a failure exists between phases or turns of the winding, these effects will not normally be reflected in variations of the insulation resistance to ground. In some instances high resistance values may be noted despite the presence of punctures in the insulation. For the above reasons insulation-resistance measurements should always be supplemented by a thorough visual inspection of the insulation before arriving at conclusions relative to the condition of the insulation, and in some instances additional tests may be required.

6-13. WHEN TO MAKE INSULATION-RESISTANCE MEASUREMENTS

1. Insulation-resistance measurements on generators and motors should be made periodically at the intervals prescribed in Chap. 7.

2. These measurements should be taken immediately after shutdown when the machine is still hot. When machines are operated at overloads or are exposed to moisture, water, salt spray, dust, etc., or when consistently low values of resistance are obtained, tests should be made more frequently. In addition to measurements taken when the machine is hot, tests should also be made occasionally when the machine is idle and at room temperature. Measurements taken when the machine is cold furnish data concerning the effects of moisture and temperature on the insulation resistance of a machine. Readings at room temperature are also needed for checking insulation resistance of stored parts such as armatures and field coils and for checking complete machines which are being stored or which have not been operated for appreciable lengths of time. Cold tests taken prior to placing a machine in service are especially valuable for ascertaining whether the insulation is suitable after long periods of idleness or after exposure to excessively humid or dirty conditions or to water, shock, etc. Insulation tests should also be taken after a machine has been repaired or serviced and on all new machines before they are placed in service and prior to and after dielectric tests.

3. Where permanently installed ground-detector voltmeters are provided, the readings indicated by the voltmeter should be observed at least once each watch if the circuit is energized. The ground-detector voltmeter is, of course, not capable of being used when the circuit is not energized.

6-14. ISOLATING THE MACHINE

1. For preliminary measurements it is usually not essential to isolate the machine completely if isolation cannot be readily accomplished. Disconnect as much of the connecting cable and associated equipment as is practicable by opening line switches, circuit breakers, and contactors. The insulation-resistance measurements taken in this manner will include the effect of the cable and equipment which is still connected. If the value of insulation resistance is lower than judged to be satisfactory, the machine must be further isolated by disconnecting the cable at the machine and repeating the tests. If the insulation resistance of the circuit within the machine still measures too low, the internal connections should be disconnected, proceeding progressively to measure the insulation resistance of individual windings, coils, etc., until the low-

resistance portion is located. Shunt field circuits may be broken up by disconnecting the leads connecting successive poles. Armature winding may be isolated by lifting all the brushes off the commutator. Phase windings may be isolated from each other where terminals for both ends of each phase are provided. Brush-holder stud insulation may be measured separately when the brushes are lifted and the connections to the bus rings broken.

2. Breaking the circuit up into its component parts may not be necessary if the low insulation resistance is suspected to be due to some general unsatisfactory over-all conditions, such as the presence of excessive moisture in the insulation, condensation on its surfaces, or accumulations of foreign matter. In such cases corrective steps may be taken and further tests made to determine whether the insulation resistance has been improved without breaking the internal connections within the machine.

6–15. CIRCUITS TO BE MEASURED

1. For d-c machines the shunt field circuit and the armature circuit (including interpoles, series fields, brushes, and brush rigging insulation) should be tested separately except in the case of small-size machines which may have one of the shunt field leads connected internally to the armature circuit. For a-c machines the armature winding and field winding should be tested separately in all cases. When measurements are being made on one winding, all other windings should be connected to ground.

2. All measurements should be made with the test voltage applied between the copper conductors and the metallic structure in which the winding is embedded. If necessary, a good connection should be assured by removing paint or any corrosion at the point of contact on this structural part. Any bare copper surface or terminal will be suitable for making the copper contact.

3. When testing rotor windings, the test voltage should be applied between the copper conductors and a metallic part of the rotor rather than the stator in order to eliminate the insulating effect of oil in the bearings.

6–16. RECORDS OF INSULATION RESISTANCE

1. The best indication of the condition of insulation is given by a comparison of the observed insulation resistance with previously measured values. A change from the last measured value has more significance than the numerical value. A uniform and consistent procedure in making measurements is essential to establish the general trend of insulation-resistance values and show any significant deviations from this trend. Permanent records of insulation resistance and pertinent data should be kept on the resistance-test record card (NavShips 531) for each machine and circuit listed in Chap. 7. For machines, this card should be kept with the associated machinery history card, electrical, NavShips 527A. The following data should be recorded:

a. Date.

b. Machine or circuit identification.

c. Value of armature insulation resistance between conductors and ground.

d. Value of field winding insulation resistance between conductors and ground.

e. Amount of cable or other connected equipment connected to machine under test.

f. Actual or estimated temperature of winding under test.

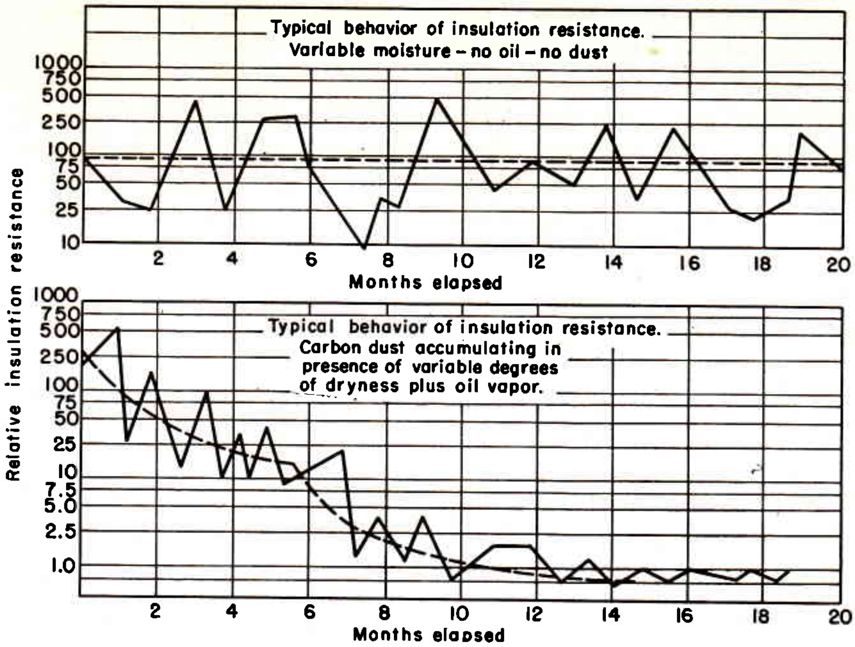


FIG. 6–9. Typical behavior of insulation resistance.

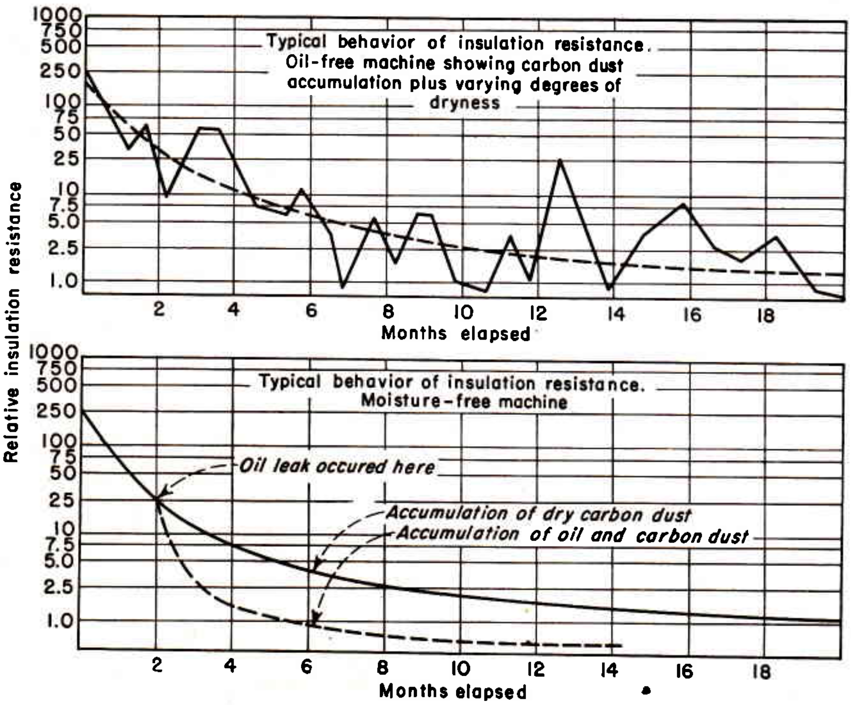


FIG. 6–10. Typical behavior of insulation resistance.

g. History of conditions preceding test such as load, operating temperatures of windings and ventilating air, room temperature and humidity, and weather conditions over past few days.

2. Curves showing the value of insulation resistance plotted against time are particularly useful for showing the trend of insulation-resistance values. The resistance-test record card (NavShips 531) provides a convenient form upon which to draw the curves. Figures 6-9 to 6-11 show the general trend which may be obtained over a period of time for large d-c motors and generators. It is recommended that a new curve be started for each machine every time the machine is given a thorough cleaning by yard, base, or tender force or after each yard, base, or tender overhaul. It should be noted that the ordinates of Figures 6-9 to 6-11 are plotted with a logarithmic scale.

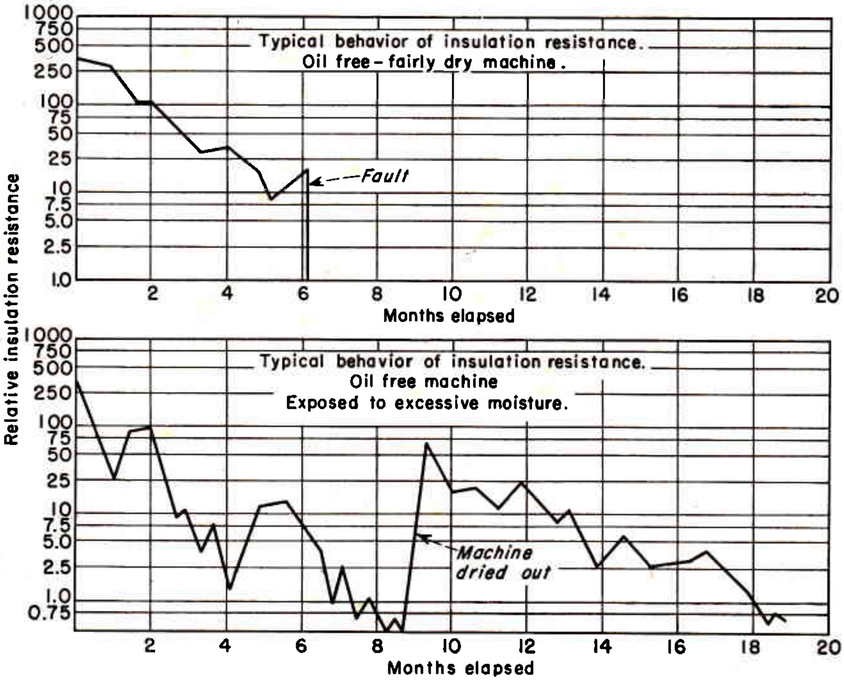


FIG. 6-11. Typical behavior of insulation resistance.

6-17. INTERPRETING MEASUREMENTS OF INSULATION RESISTANCE

The following conclusions based on practical service experience should be of assistance in understanding what values and variations in insulation resistance may be considered normal and abnormal and in deciding what corrective measures should be taken when abnormal conditions are encountered:

1. New machines or new windings may have relatively low values of insulation resistance and still be perfectly fit for service.

2. After the period of time required for the varnish to dry has elapsed, the insulation resistance of a winding or circuit in good condition may be expected to decrease gradually with age if no variations in moisture content, temperature, or cleanliness occur.

3. Periodic tests in service are useful in detecting weaknesses of insulation or accumulations of moisture or dirt. Such conditions are usually indicated by marked decreases in insulation resistance. Hence periodic measurements serve to determine when cleaning, drying, or other servicing of the machine is necessary.

4. A high value of insulation resistance is not always proof that the insulation is in good condition. For this reason, complete and thorough inspections should be made regularly in addition to the periodic tests of insulation resistance.

5. When measuring resistance, if the instrument pointer requires appreciable time to reach a steady value, the insulation is usually relatively dry and clean. If the instrument pointer becomes steady quickly and the resistance is low, there is a strong possibility that the insulation is moist, dirty, or damaged.

6–18. DISPERSION OF INSULATION-RESISTANCE DATA

It will be found that on duplicate machines there will be a relatively wide dispersion of insulation-resistance data. Where statistical studies have been made on a large number of duplicate machines, it has been found that there is a central tendency of the data. However, the spread is quite wide, and unless a study can be made of such a group of identical windings, it may be thought that there is no significance to insulation-resistance data or correlation with the resistivity of the basic insulating material.

Figure 6–12 shows the results of a statistical study on insulation resistance of 700 identical d-c motors for DE vessel propulsion. Figure 6–13 shows the correlation of a corresponding study on 120 large a-c machines (many were troopship propulsion motors) that were similar though not identical.

Attempts have been made to express insulation resistance as a precise function of rating in kilovolt-amperes (or kilowatts) and speed. This is a reasonable approximation but must not be assumed to be a precise formula following a natural law. It has been found that factors other than the dimensions influence machine insulation

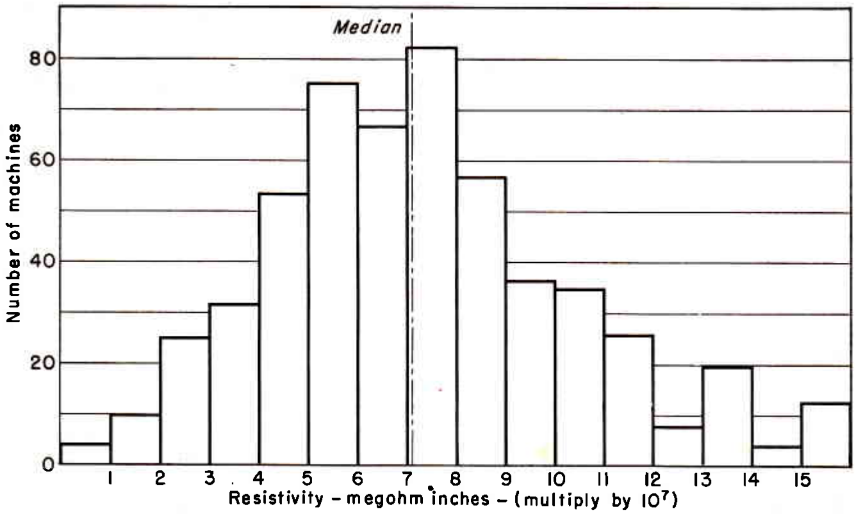


FIG. 6–12. Frequency distribution of volume resistivity of 700 identical d-c marine propulsion motors. (*Johnson and Weil, Westinghouse Electric Corp.*)

resistance to a greater extent than slot area and insulation wall thickness. For example, leakage resistance of the end windings and creepage surfaces will predominate on machines in service, particularly on d-c machines which have relatively great creepage areas from exposed conducting parts. These factors contribute to the width of the range of observed insulation-resistance values.

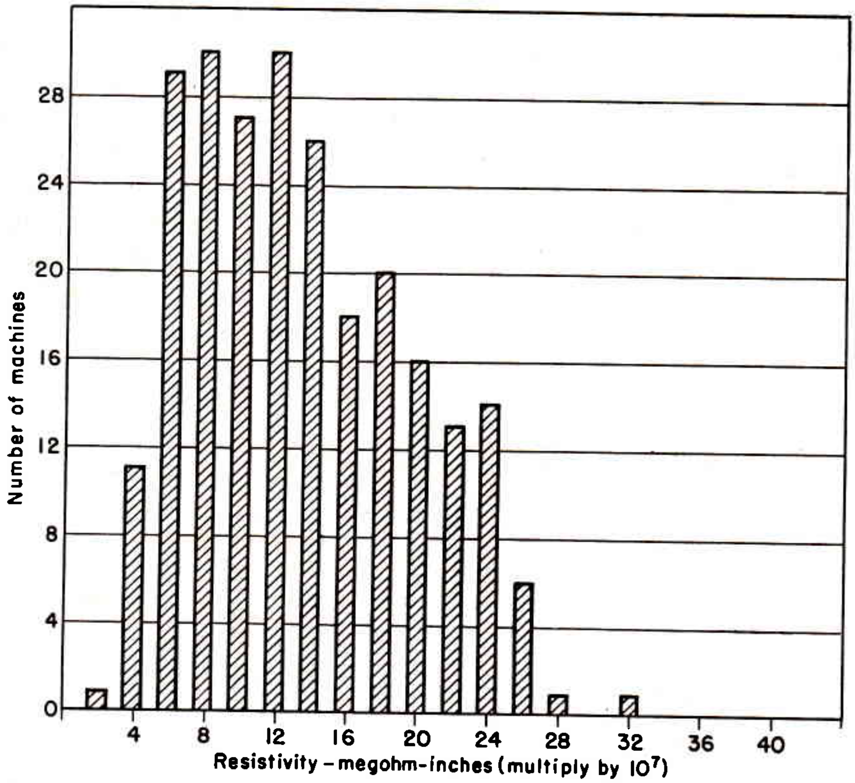


FIG. 6–13. Frequency distribution of volume resistivity of class B insulation on large a-c motors. (*Johnson and Askey, Westinghouse Electric Corp.*)

6–19. DIELECTRIC ABSORPTION TEST

The dielectric absorption test is an extension of insulation-resistance tests for longer time than the conventional 1-minute period. To take such tests a motor-driven megohmmeter or an electronic-type megohm bridge is required. A hand-cranked megohmmeter will not give sufficiently close voltage regulation for long-time tests as required to determine dielectric absorption. In these tests the insulation resistance should be read frequently at various time intervals after voltage application, and the data plotted as a function of time. Figure 6–14 shows such a curve. The test should be continued until three successive readings show no change, or for about 10 minutes total. Clean, dry insulation that is in good condition will have a steep slope of resistance vs. time as well as a high level of insulation resistance. Dirty or moist insulation will quickly reach a stable value of insulation resistance, usually at a lower absolute value.

Polarization index is an adaptation of the dielectric absorption test and provides an

easy way to evaluate the results. The polarization index is the ratio of the 10-minute insulation resistance to the 1-minute insulation resistance. This is sometimes expressed as a formula:

$$\text{Polarization index} = \frac{R_{10}}{R_1}$$

where R_{10} = insulation resistance after 10-minute voltage application.
R_1 = insulation resistance after 1-minute voltage application.

A polarization index of 3 to 4 is excellent. If it falls to 1.5 or less, incipient trouble may be indicated.

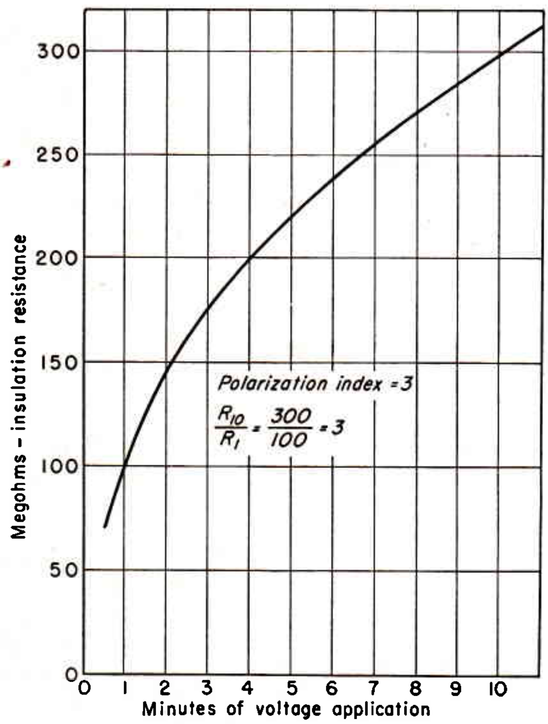


FIG. 6–14. Typical dielectric absorption curve.

6–20. MAINTENANCE TESTING OF WINDINGS

Important principles concerning the proper methods of testing as a maintenance procedure can be summarized as follows:

1. Testing insulation at voltages greater than the operating voltage but less than the air breakdown for the spacing gives limited assurance of the absence of seriously conducting paths in the insulation wall.

2. Testing insulation at voltages approaching the region of probable breakdown is known to be damaging. The exact extent of such damage depends upon how nearly the breakdown region is approached. On older insulation it should be assumed that this region may be only slightly above the equivalent breakdown of the air space.

3. Repeated overpotential tests are employed as maintenance procedures by many users. However, there is no concrete data indicating the desirability of such overpotential tests. The major justification of overpotential tests as a maintenance procedure is to produce failures at a time and place when repairs can be made most conveniently. However, the problem of weeding out defective insulation without damaging usable insulation has not been completely solved. Overpotential tests should never be made when failure would result in serious inconvenience.

4. Insulation-resistance tests are generally considered to be nondestructive and satisfactory maintenance tests.

Where a-c dielectric proof tests are to be made in service on old windings, the voltage of the test requires careful consideration. It is generally not advisable to apply an overpotential test greater than 75 percent of the 1-minute proof test applied when the winding was new. Generally such tests range from 60 to 75 percent depending upon the age and condition of the winding. Before any overpotential test is made, the insulation resistance should be checked. No overpotential test should ever be made if the insulation resistance is abnormally low. An a-c test of less than one and one-half

times the normal operating voltage is not advisable, as it cannot be expected to detect faults. However, a d-c test of equivalent value may be helpful if the leakage current is studied.

It is always desirable in maintenance testing to make an insulation-resistance check before and after an overpotential test. A significant difference in such values should be investigated before returning the machine to service.

6–21. EMERGENCY TEST METHODS

When no conventional test equipment is available, it may be necessary to devise some emergency test apparatus. It is difficult to foresee exactly what problems may arise and what material may be available from which to make emergency test equipment. However, certain general principles can be discussed which will enable a skilled technician or engineer to invent some emergency test facilities for the particular job at hand. To test insulation it is necessary to have available a suitable voltage source and a means for detecting an abnormal conductivity condition in the insulation.

At commercial frequencies ac is desirable because of the ease of voltage transformation and because it simulates the operating condition of most machine insulation. Where such ac is not available, dc may be used in an emergency. Obviously a d-c voltage of the same value as the a-c rms voltage is by no means comparable in searching for insulation faults. At the very least the d-c voltage would have to be equal to the peak value of the a-c (1.41 times the rms voltage). However, this is not equal in destructive effect because there is no dielectric loss, such as produced by ac. Therefore, for practical test work, a d-c voltage should be equal to about 1.6 times the a-c rms test voltage which would normally be used. One advantage of a d-c emergency test of ground insulation is that there is no effect of a limited power supply such as exists with an a-c test. Therefore, even small-capacity battery supplies, such as radio B batteries, can be used. On shipboard there are likely to be sources of high-voltage dc in radio equipment. The detection of a fault with a low power source may require considerable ingenuity. Milliammeters or microammeters are generally suitable. Low-power lamps (such as a neon glow tube) can be used to advantage in this connection by using them in series with the test voltage or with a suitable resistor shunted across them.

In the detection of any fault, it is necessary to establish some criterion by which damaged coils or insulation can be detected. This can generally be done by making comparative tests on coils known to be good and those which are suspected.

The turn testing of coils in a winding where individual turns cannot be separated may present numerous difficulties. High-frequency or surge tests are out of the question unless highly specialized equipment is available. The simplest and best method is to segregate the winding into small enough parts so that low-voltage ac (from a light circuit) can be applied to these parts separately and voltmeter-ammeter readings taken of the current through the winding. The resultant voltage on the individual turns should be appreciably more than operating turn voltage or serious faults may not be found. There need be no fear in applying a-c voltages of 220 volts or less that the voltage stress will damage any good insulation, as a voltage of this value will not break down any solid insulation or jump any positive separation between two adjacent conductors. Any

faults detected by this means will have existed prior to the test.

When tests have been made on ground insulation using emergency test methods with unproved means for detecting faults, it is desirable to double-check the results of such a test. Therefore, it would be well to test the winding to ground with a megohmmeter before and after such a proof test is made. If there is no observable difference in the reading before and after the emergency test, it is reasonable to assume that the insulation withstood the test.

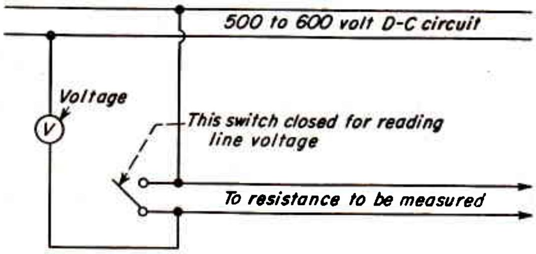


FIG. 6–15. Diagram of voltmeter method of measuring insulation resistance.

An emergency method of making insulation-resistance tests employs a d-c voltmeter, preferably a meter with high internal resistance. This method is based on the principle of comparing a current in a known resistance under two conditions. The voltmeter is first connected directly across a d-c source as shown in Fig. 6–15, and its deflection observed. Then the voltmeter is connected in series with the insulation whose resistance is unknown and connected across the same d-c voltage source. The resistance of the unknown voltage source can then be determined from the following formula:

$$R_u = \frac{R_v(E_l - E_o)}{E_o}$$

where R_u = unknown insulation resistance.
R_v = resistance of the voltmeter.
E_l = voltage of the line.
E_o = observed voltage with voltmeter in series with unknown resistance.

7. Preventive Maintenance Program

The maintenance of electrical apparatus is principally the maintenance of insulation. Bearings, commutators, and collectors require periodic attention but can usually be continued in operation at least until an orderly shutdown may be arranged. However, when insulation fails, it is considered extremely fortunate if only a temporary shutdown results. It is important to have a comprehensive understanding of the characteristics of insulating materials if incipient failures are to be discovered by the maintenance man before trouble occurs. A motor insulated for a furnace or boiler-room application might fail very soon if applied to a sump pump or to certain deck-type winch motors. The converse is also true, as good moisture-resisting insulations are not necessarily the most suitable for very-high-temperature service.

Preventive maintenance work is preferable to replacement or repair after trouble occurs. It is based on the theory that "it is better to **keep** out of trouble than to **get** out of trouble." But if trouble does occur, temporary repairs made with poorly selected insulating materials may result in personal injuries or in failure of the apparatus. For best results use only insulating materials developed through years of research and experience by reliable manufacturers of materials and apparatus for specific applications. These are the materials listed in Appendix I which have Navy and electrical manufacturers' approval.

7-1. PREVENTIVE MAINTENANCE PROGRAM

The insulation of electric machinery does not require extraordinary care to maintain it in satisfactory operating condition. However, it can be assured of more reliable service if a planned inspection and maintenance program is carried out. Such a program should include several basic items as follows:

1. Make regular inspections, which should be as thorough as circumstances permit.
2. Record troubles and corrective measures taken for each important piece of machinery and for all machines where possible. Such data are of great value in determining causes and guiding the selection of preventive measures.
3. Provide spare units, coils, or component parts wherever possible.
4. Keep the spare units, renewal parts, and insulating supplies in clean, dry condi-

tion so that they may be quickly used to best advantage.

5. Schedule major inspections, or arrange in advance for planned maintenance work which may be disclosed by the regular inspection.

New installations of electric machinery should be carefully watched in the early stages of service. Unusual operating conditions can sometimes be found and corrected before major damage has occurred. Excessive temperature for the particular class of insulation used will greatly reduce the life of a winding. Excessive humidity within the machinery may cause short circuits or grounds unless the apparatus is specially designed for such operating conditions. Even where it is designed for high-humidity conditions, frequent inspection may save a service interruption. Extra care consisting of frequent inspection and maintenance is advisable for all machinery operating under conditions that are known to be severe.

Keep records of the inspection and tests made on each machine. Include troubles found and corrected.

Summary:

Inspect electric machinery regularly.

Know the condition of the apparatus at all times.

Know what loads the machinery must carry.

Keep windings and creepage surfaces free from dirt, oil, and chemical contaminants.

Investigate any trouble, and correct conditions before failure occurs.

Preventive maintenance is better than emergency repair after failure occurs.

7–2. INSPECTION SCHEDULE

Inspection provides advance notice of trouble. An intelligent, conscientious, observant inspector is a very valuable asset. He can greatly improve the reliability of electric machinery by determining when preventive maintenance is required. It is of greater value to have inspections made by competent personnel in a conscientious manner at longer intervals than to have inadequate but more frequent inspections by poorly trained personnel. For a schedule of inspection for shipboard electrical equipment refer to "Bureau of Ships Manual," Chap. 60.

7–10. MINIMUM VALUES OF INSULATION RESISTANCE

It is impossible to set a rigidly fixed value for the minimum permissible insulation resistance on a machine and state positively that, if the machine has an insulation resistance below the minimum value, it will fail or that, if it has an insulation resistance above the minimum value, it will operate satisfactorily. Machines can and have operated satisfactorily over extended periods of time with low insulation resistance. Conversely, a high value of insulation resistance is alone not sufficient to ensure satisfactory operation. Nevertheless, despite those limitations, experience has made it possible to set up limiting values of insulation resistance which serve to indicate the values that should be maintained on machines in service and also serve to determine the nature of the treatment that should be given electrical equipment when it is overhauled. These values are shown in Tables 1 to 4, Fig. 7–1, inclusive, which are explained in Sec. 7–11.

7–11. *Explanation of Tables*

Tables 1 to 4, Fig. 7–1, give insulation-resistance values for four types of machines. For each machine, three sets of insulation-resistance values are given: before cleaning, after cleaning in the vessel, and after reconditioning in a shop. The following notes

FIG. 7-1. TABLE 1. DIRECT-CURRENT GENERATORS AND MOTORS
(Except propulsion generators and motors and auxiliary generators for submarines)

Circuit	Insulation resistance in megohms at 25 C*		
	Before cleaning	After cleaning in vessel	After reconditioning in shop
Complete armature circuit†	0.1	0.5	1
Armature alone	0.2	1	2
Armature circuit less armature†	0.2	1	2
Complete shunt field circuit†	0.5	1.25	2.5

* The figures given are for machines rated at 250 volts or less. For machines having a rated voltage E greater than 250 volts, multiply all figures given in the table by $\frac{E}{250}$.

† Small machines usually have one of the shunt field leads connected internally to the armature circuit. To avoid disassembly in such cases, the complete armature circuit and complete shunt field circuit may be measured without breaking this connection. If necessary, the armature can then be isolated by lifting all brushes.

With the brushes left in place, the complete armature circuit will include armature, armature circuit, and the permanently connected shunt field circuit. The values given in the table for the complete armature circuit will apply.

With the brushes lifted, the armature circuit less armature and the complete shunt field circuit will be measured. The values given in the table for armature circuit less armature will apply.

FIG. 7-1. TABLE 2. DIRECT-CURRENT PROPULSION GENERATORS AND MOTORS FOR SURFACE VESSELS AND SUBMARINES AND DIRECT-CURRENT AUXILIARY GENERATORS FOR SUBMARINES

Circuit	Insulation resistance in megohms at 25 C		
	Before cleaning	After cleaning in vessel	After reconditioning in shop
Complete armature circuit	$R \times 0.3$	$R \times 1.5$	$R \times 3$
Armature alone	$R \times 0.5$	$R \times 2.5$	$R \times 5$
Armature circuit less armature	$R \times 0.5$	$R \times 2.5$	$R \times 5$
Complete shunt field circuit	$R \times 2$	$R \times 5$	$R \times 10$

Where $R = \dfrac{E}{\dfrac{KW}{100} + 1{,}000}$

and E = rated voltage of generator or motor.
KW = kilowatt rating of generator = horsepower rating of motor $\times$ 0.746.

FIG. 7–1. TABLE 3. ALTERNATING-CURRENT GENERATORS AND MOTORS OTHER THAN PROPULSION GENERATORS AND MOTORS

Circuit	Insulation resistance in megohms at 25 C*		
	Before cleaning	After cleaning in vessel	After reconditioning in shop
Stator circuit of generators and motors	0.2	1	2
Rotor circuit of wound-rotor induction motors	0.1	0.5	1
Field circuit of generators or of synchronous motors	0.4	2	4

* The figures given are for machines rated 500 volts or less. For machines having a rated voltage E greater than 500 volts, multiply all figures given in the table by $\frac{E}{500}$.

FIG. 7–1. TABLE 4. ALTERNATING-CURRENT PROPULSION GENERATORS AND MOTORS

Circuit	Insulation resistance in megohms at 25 C		
	Before cleaning	After cleaning in vessel	After reconditioning in shop
Stator circuit of generators and motors	$R \times 0.4$	$R \times 2$	$R \times 4$
Rotor circuit of wound-rotor induction motors	$R \times 0.2$	$R \times 1$	$R \times 2$
Field circuit of generators or of synchronous motors	0.4	2	4

Where $R = \dfrac{E}{\dfrac{KVA}{100} + 1{,}000}$

and E = rated line-to-line voltage.

KVA = rated kilovolt-amperes.

FIG. 7–1. Minimum values of insulation resistance for various types of Naval machinery.

contain information which should be kept in mind when using the tables.

1. All figures are for insulation-resistance values at 25 C (77 F). If measurements are made at temperatures different from 25 C, the measured values should be corrected to 25 C by the use of the alignment chart given in Fig. 6–8. See Sec. 6–12 for instructions on the use of this chart.

2. All figures are **minimum** values. Insulation resistances well above the minimum values are normally obtainable. Every reasonable effort should be made to maintain insulation resistances at values considerably higher than those given in the tables.

3. The complete armature circuit of a d-c machine includes the armature, brush rigging, connections to machine terminals, and any fields which carry armature current, such as commutating field, compensating field, and series field.

4. The stator circuit of polyphase generators and motors and the rotor circuit of

wound-rotor induction motors include all phases. When a single phase is isolated, its insulation resistance should be at least three times the value given in Table 3 or 4 if the machine has three phases or at least two times if the machine has two phases (used in some electric propulsion equipment).

5. The word "cleaning" as used in Tables 1 to 4, inclusive, of Fig. 7-1 includes thorough cleaning of the machine and such maintenance as drying the machine by means of external heat, by energizing the windings, or by the use of a desiccant and does not include such minor maintenance as wiping commutators or slip rings.

7-12. *Insulation Resistance of Machines in Service*

The figures given in the "Before cleaning" columns of Tables 1 to 4, Fig. 7-1, are the values of insulation resistance at or below which machines should be removed from service and thoroughly cleaned, dried out, or repaired as necessary. Values less than those given in the "Before cleaning" columns should not be construed as necessarily indicating an unsafe condition or one which would prohibit the use of a machine if necessary. However, when values less than those are obtained for a machine, use of the machine should be avoided if practicable and action should be taken at the first opportunity to find and remedy the cause of the low insulation resistance. Very often the cause of abnormally low insulation resistance may be suspected from the nature of the operating conditions prior to the test which showed low insulation resistance.

1. If the machine has been exposed to excessive moisture, has been splashed with water, or has been shut down for a long period, the need for drying out the insulation is manifest. If the machine has been exposed to excessive dust or dirt, as when the commutator is stoned or the brushes seated, or if a visual inspection indicates that the machine is in a dirty condition, the need for cleaning it is evident. Frequently visual inspection will reveal physical damage that has occurred and caused abnormal measurements to be obtained.

2. If the cause of the abnormal condition cannot be readily ascertained as noted above, resistance measurements should be taken on the component parts of the circuits within the machine, including, if necessary, individual field coils, internal leads, brush-holder insulation, slip rings, etc. Often a defective lead or deposits of dirt on exposed terminals or brush insulation are the causes of low insulation resistance to ground. In such cases the defective part should be thoroughly cleaned and its insulation resistance checked again.

3. If the trouble cannot be located by following the above procedure, inspect the end windings for accumulations of dirt, dust, or other foreign matter and for signs of damage.

4. If the trouble cannot be localized, the machine should be dried out, thoroughly cleaned, and carefully inspected to check the condition of the entire machine.

5. If the machine still has an insulation resistance which is below the value given in the "After cleaning in vessel" column of the applicable table in Fig. 7-1, the trouble is probably due to a general or local weakness of the insulation. Unless the insulation resistance is below the value given in the "Before cleaning" column of the applicable table, the machine may be placed in service but should be checked every few days. If the insulation resistance remains low for a continued period, the machine should be taken out of service for repair and overhaul. If the insulation resistance is below the value given in the "Before cleaning"

column of the applicable table, the machine should not be used, except in case of emergency, until it can be reconditioned by shipyard or base forces.

7–13. *Insulation Resistance as a Guide in Overhaul*

Insulation-resistance measurements serve as a useful guide to determine the nature and amount of work that should be done in the overhaul of electric equipment. The following instructions apply except for the complete overhaul of electric propulsion equipment which is made at periodic intervals.

1. Select from Tables 1 to 4 of Fig. 7–1 the particular table applicable to the machine under consideration.

2. Before cleaning the machine or doing any overhaul work, measure the insulation resistance of the largest circuits listed in the applicable table. These will be the complete armature circuit and the complete shunt field circuit for d-c machines, the stator circuit and field circuit for a-c generators, etc.

3. If the insulation resistance of the circuit is less than the value given in the "Before cleaning" column of the applicable table, break the circuit up into its component parts and measure their insulation resistances to locate the part or parts responsible for the low insulation resistance. Remove these parts (or all parts of the circuit if the trouble cannot be traced to specific parts) to a shop for a thorough reconditioning. Clean the remaining parts in the machine.

4. If the insulation resistance of a circuit before cleaning is greater than the value given in the "Before cleaning" column of the applicable table, clean the circuit in the machine without disassembly except for removal of access plates.

a. If the insulation resistance after cleaning is greater than the value given in the "After cleaning vessel" column of the table, and if visual inspection gives no evidence of defects, the circuit is suitable for service.

b. If the insulation resistance after cleaning is less than the value given in the "After cleaning in vessel" column of the applicable table, break up the circuit into its component parts and measure their insulation resistances to locate those responsible for the low insulation resistance. Remove these to a shop for a thorough reconditioning. If the trouble cannot be traced to any specific parts, repeat the cleaning of the entire circuit in the machine. If the insulation resistance is still less than the value given in the "After cleaning in vessel" column of the table, the entire circuit should be thoroughly reconditioned in a shop.

5. The insulation resistance of a circuit or winding which has been reconditioned in a shop should be greater than the value given in the "After reconditioning in shop" column of the applicable table.

6. Circuits and windings which have been reconditioned in a shop and which have insulation resistance in accordance with Sec. 7–10 should be given a high-potential test by the shop which has done the reconditioning provided the shop is equipped with high potential test facilities. A high-potential test should not be made on circuits which have been cleaned in the machine but not reconditioned in a shop or on any winding in which the insulation resistance is less than that given in the "After reconditioning in shop" column of the applicable table in Fig. 7–1.

7–14. *Example*

1. Assume that a submarine becomes available at a Naval shipyard or other over-

haul activity and that the cleaning (not the complete overhaul) of a propulsion generator is to be undertaken. Since the machine is a d-c propulsion generator, Table 2 of Fig. 7-1 applies. The rating of the generator is 415 volts, 1,100 kilowatts. The temperature of the generator is 25 C (77 F), and the machine is dry. For this generator:

$$R = \frac{415}{\frac{1,100}{100} + 1,000} = 0.41 \text{ megohm}$$

Table 2 then becomes (for this particular generator):

Circuit	Insulation resistance at 25 C, megohms		
	Before cleaning	After cleaning in vessel	After reconditioning in shop
Complete armature circuit	0.12	0.61	1.2
Armature alone	0.20	1.0	2.0
Armature circuit less armature	0.20	1.0	2.0
Complete shunt field circuit	0.82	2.0	4.1

vessel" column, indicating that the armature is satisfactory for service.

d. The measured value of insulation resistance of the armature circuit less armature is found to be 0.75 megohm, which is less than 1.0 megohm, the value in the "After cleaning in vessel" column, indicating that the armature circuit less armature needs additional cleaning or that there is some isolated low-resistance path. The brush rigging, after being disconnected from the combined commutating and compensating winding by removing the flexible connector between them, is found to measure

2. *Complete Armature Circuit.* Assume that the following conditions prevail:

a. Measured value of insulation resistance of complete armature circuit is 0.16 megohm. This value is greater than 0.12 megohm, the value in the "Before cleaning" column of the table. The complete armature circuit is, therefore, cleaned in place.

b. After cleaning, the measured value of the insulation resistance of the complete armature circuit is 0.45 megohm, which is less than 0.61 megohm, the value in the "After cleaning in vessel" column.

c. The armature alone is disconnected from the complete armature circuit, and the armature is measured alone, giving a value of 1.2 megohms, which is greater than 1.0 megohm, the value in the "After cleaning in

5 megohms. The winding measures 0.8 megohm, indicating a low-resistance path to ground somewhere in the winding. The combined commutating and compensating winding is then disconnected pole by pole, and each pole is measured separately. It is found that one commutating field pole has lower insulation resistance than any of the other commutating field poles. Upon further investigation it is found that one of the less accessible spots on the pole has not been adequately cleaned, and after this place is cleaned, the insulation resistance of the pole in question is measured and found to be equal to all the other poles. All parts of the armature circuit less armature are then reconnected, and the insulation resistance measured, giving a value of 1.8 megohms,

which is greater than 1.0 megohm, indicating that these parts are satisfactory for service. The armature is then connected in the circuit, and the complete armature circuit gives a measured insulation-resistance value of 0.75 megohm, which is greater than 0.61 megohm, and the complete armature circuit is ready for service.

3. *Shunt Field Circuit.* The measured value of insulation resistance of the complete shunt field circuit before cleaning is 0.10 megohm, which is less than 0.82 megohm, the value in the "Before cleaning" column. Each shunt field coil is disconnected and tested separately, and one coil is found to have much lower insulation resistance than any of the other coils. This coil is removed, and it is found that the insulation between the coil and the metal pole piece has been damaged, allowing a low-resistance path to ground. The damaged insulation is renewed, and all the shunt field coils cleaned and reconnected. The insulation resistance then measures 3.5 megohms, which indicates that the complete shunt field circuit is ready for service.

7–20. SAFETY PRECAUTIONS WHILE WORKING ON ELECTRICAL EQUIPMENT

Before attempting any maintenance or repair work on electrical equipment, be sure that the equipment is disconnected from the power supply and that it cannot be inadvertently energized by someone who does not know of the work being performed. If there is any doubt as to whether the supply circuits have been de-energized, they should be checked with a voltmeter or voltage tester. Check the wiring diagram to determine if there are any condensers that should be discharged by connecting their terminals to each other and to ground by use of a wire on an insulating handle. An exception to the rule for de-energizing the equipment may be made when it is necessary to observe operation. In this case, observe the safety precautions necessary to prevent shock or arcs which might start fires or ignite explosive vapors.

7–21. PURPOSE OF MAINTENANCE

1. Electrical equipment will function satisfactorily provided that:

a. All circuits are connected correctly.

b. Electrical contacts are clean, tight, and of low resistance.

c. Moving parts function freely and in the way they are designed to operate.

d. Electrical insulation is in good condition—clean, dry, and of high resistance.

2. The purpose of maintenance is to see that these conditions are satisfied and that the equipment is in all respects ready for service.

7–22. PERIODIC CLEANING AND INSPECTION

A regular schedule of cleaning and inspection will go far toward ensuring trouble-free operation and the detection of incipient faults before they develop sufficiently to be a major source of difficulty. Where definite times for cleaning and inspection are not specified for different types of equipment, each ship should set up a practicable schedule for periodic cleaning and inspection at intervals sufficiently short to keep the equipment in good shape. In setting up such a schedule the following points should be kept in mind:

1. New equipment should be carefully watched until extended operation has demonstrated that it is performing satisfactorily.

2. Old equipment requires more frequent cleaning and inspection than similar equipment which has seen less service.

3. Time spent in cleaning, inspecting, and correcting defects before they grow serious means time saved in overhauls and repairs.

7–23. RECORDS AND REPORTS

1. *Maintenance Records.* These add greatly to the value of inspection. Records which reveal progressive deterioration and repetition of repair jobs indicate the necessity for a deeper investigation into the cause of trouble. Reports based upon such records form the basis for changes in design, application, or method of operation to eliminate future faults and difficulties, increase the ease and dependability of operation, and ensure the safety of personnel and long life of equipment. The records and reports which are of particular importance in connection with maintenance of equipment are the ship's material history, the current ship's maintenance project, and engineering trouble reports.

2. *Ship's Material History.* A history should be kept on board each ship on Machinery History Cards, Electrical (NavShips 527A), with a separate card for each major item of power and lighting equipment. Examples of items for which cards should be kept are:

Propulsion generators and exciters.

Propulsion motors.

Propulsion control cubicles and stands.

Ship's service and emergency generators and exciters.

Electrically driven forced-draft blowers, lube oil purifier motors, boiler feed pump and condensate pump motors, steering gear motors, etc.

Magnetic mine-sweeping generators, exciters, and control equipment.

When the card for an item is full, the history should be continued on another card. The history kept on the card should include a complete record of all measurements and tests; of all difficulties, troubles, or derangements; of the methods used to restore the equipment to service; and of all work done on the equipment whether by the forces afloat, at a Naval shipyard, or elsewhere. All pertinent data and dates should be entered. Entries should be arranged in chronological order. In addition to the history card, a resistance-test record card (NavShips 531) should be kept for power, lighting, and degaussing circuits and for each item of electrical rotating machinery which is essential to the continued operation of the ship's propulsion plant or to the functional operation of the vessel. Examples of such equipment are:

Propulsion generators and exciters.

Propulsion motors.

Ship's service and emergency generators and exciters.

Electrically driven forced-draft blowers, lube oil purifier motors, boiler feed pump and condensate pump motors, steering motors, etc.

Magnetic mine-sweeping generators and exciters.

3. *Engineering Trouble Reports.* Whenever engineering trouble occurs, one copy of the Report of Engineering Trouble (Engineering Sheet 4, OPNAV 34E–158) should be sent directly to the Bureau of Ships. A thorough report should be prepared even if the derangement is considered to be due to faulty installation, operation, or maintenance rather than defective design or manufacture. Such information is needed in order to design equipment which will reduce or eliminate the possibility of similar occurrences. Facts are wanted together with comments on the cause and results of the trouble. A report which merely states that a failure has occurred furnishes no information upon which to base action to prevent similar failures in the future. A report should include, in full detail, observations

made prior to, during, and after the failure. Specific items to be covered in reports of trouble with electric power and lighting equipment include:

a. A complete identification of the equipment concerned. This will include the name of the manufacturer, complete nameplate rating, and serial number.

b. The results of measurements made with portable or switchboard instruments. The measurements should be as complete as conditions permit.

c. In the case of winding or insulation failure, every effort should be made to determine the actual cause of failure and report the findings in detail. The common causes are:

(1) Overloads. These are characterized by excessive heating and relatively uniform charring of insulation.

(2) Foreign materials entering or accumulating on insulation, such as oil, dirt, water, abrasive, or conducting materials.

(3) Defective Insulation. This is usually characterized by localized heating and charring of insulation.

(4) Defective Wire.

(5) Defective connections between coils or between coils and supply leads.

(6) Mechanical damage to insulation during installation, maintenance, or overhaul.

(7) Mechanical trouble in motor-driven auxiliaries, such as tight packings, rubbing runners, leaking glands, hot bearings, vibration, or other troubles which contribute to or cause the electrical derangement.

7-24. PAINTING ELECTRICAL EQUIPMENT

1. Special precautions are necessary when removing paint or repainting electrical equipment. In general, the removal of paint from electrical equipment should be avoided. The use of scraping or chipping tools on such equipment is likely to injure the insulation or damage relatively delicate parts. Furthermore, paint dust is composed of abrasive and semiconducting materials which impair the insulation. All electrical equipment, such as generators, switchboards, motors, controllers, etc., should be covered to prevent entrance of the paint dust when paint is being scraped in the vicinity. After completion of the paint removal, the electrical equipment should be thoroughly cleaned, preferably with a vacuum cleaner if available.

2. Repainting of electrical equipment should be done only when necessary to prevent incipient corrosion due to lack of paint. The painting should then be confined to the areas affected. General repainting of electrical equipment or enclosures for electrical equipment for the sole purpose of improving its appearance is not desirable. **Paint should never be applied to any insulating surfaces in electrical equipment. When preservation of such surfaces is necessary, they should be coated with approved types of electrical insulating varnish or compound.**

7-30. EFFECT OF MOISTURE

Water or excessive moisture on electrical insulation decreases the insulation resistance and may result in failure of electrical equipment. While the necessity of preventing electrical equipment from being subjected to the effects of water or moisture-laden air is obvious, the various ways in which damage may inadvertently occur on shipboard installations are sometimes overlooked.

7-31. *Water from Ventilation Ducts*

Ventilation ducts and terminals near electrical equipment are a source of water

and moisture that must be considered. Experience has shown that, irrespective of the normal location of the vent openings for a ventilation system, water may get into the ducts, because of unusual sea and weather conditions, as a result of damage to some portion of the ship, or because of fire fighting or other emergency measures. Once in the ducts, the water will emerge from any parts of the ducts which are not watertight or from supply and exhaust openings. Although due recognition is given in the design of a vessel to the relation between ventilation openings and electrical equipment, subsequent changes necessitated by other considerations may overlook the importance of this matter. **Serious derangements have occurred on Naval vessels as a result of sea water or spray being discharged from ventilation ducts upon electrical equipment.** Such derangements have resulted in loss of electric power to vital functions, such as steering or control of guns, thereby endangering the military effectiveness of the vessel and in some cases contributing to its complete loss.

7–32. *Equipment to Keep Dry*

The prevention of this kind of derangement requires elimination of the possibility that water or spray entering through or collecting on ventilation ducts and terminals will drip, splash, or be blown on electrical equipment. Particular attention is necessary to protect against water or moisture damage to the following electrical equipment:

Switchboards
Generators
Generator terminals
Propulsion motors of the open type
Transformer terminals
Open-type control or distribution panels

7–33. *Avoiding Water from Ventilation Ducts*

The following suggestions are given in order that ships' forces may be aware of the changes and methods of correction which are within their own capacity of accomplishment when necessary. These are not intended to be all-inclusive or restrictive. Other conditions and corrections will be apparent upon inspection of specific vessels.

1. Where adjustable-type ventilation openings are installed so that they might inadvertently be turned to direct the air flow toward electrical equipment, the openings should be adjusted so that the air flow is directed away from the electrical equipment and secured in that position by means of bolts or welding with straps or brackets added if necessary.

2. Where vent openings of the non-adjustable type are so located that moisture-laden air may blow against the electrical equipment, baffles should be installed to prevent it. Such baffles may consist of sheet metal formed into semicylindrical shape and secured to the vent openings in such a manner that the air flow is directed away from the electrical equipment.

3. Where vent openings are so located that water might drip on electrical equipment even though the normal air flow is not directed toward it, the opening should be relocated to avoid this possibility. The duct may be shortened or extensions added to obtain such relocations. Portions of the duct or its extensions which are immediately above electrical equipment should be watertight to prevent water dripping from joints in the duct.

7–34. *Effect of Changes on Vent System*

Revisions such as those suggested above, involving change in direction of the air flow or changes in ventilation opening locations,

mysterious unpredictable cause. A number of failures of this type, when carefully studied, were found to be the result of small quantities of ionizable substances which when dry are insulators but when exposed to humidity are relatively highly conducting. The presence of such ionizable materials on insulation creepage surfaces or within the body of an insulation may produce high conductivity when exposed to humidity. The insidious behavior of such materials in insulation may allow apparatus to pass overpotential tests when dry and yet fail in service under far less severe voltage conditions, when it has been exposed to moisture. Furthermore, if these ionizable materials are covered or protected by an effective varnish coat, the winding may withstand humidification in the early stages of its life and fail subsequently. As insulation ages and the protective varnish coat deteriorates, these contaminants become a more active hazard to insulation.

There are many possible contaminants which are ionizable and which may have such deleterious effects on insulation. Acid soldering fluxes are the most likely causes of such action. Uninformed workmen, especially repairmen, will frequently use acid fluxes because they make the soldering job so much easier. The workmen do not realize the serious hazard they are building into the apparatus. There are many less obvious and equally dangerous sources of chemical contamination such as protective hand creams and even germicide additions to lubrication oils used for mold lubricants. In one case it was found that the adhesives used in attaching asbestos paper to wire contained ionizable salts. A more obvious source of contamination with ionizable materials occurs in motors that operate in chemical plants or motors that might be exposed to salt spray.

There is a great deal of service experience which indicates that insulation contaminants frequently contribute to the failure of electrical insulation. Such contaminants include moisture, salt, oil, carbonaceous materials, and dust. These contaminants are believed to affect adversely both the physical and electrical properties of electrical insulation. A series of tests made by the General Electric Company in cooperation with the Navy Department simulated a number of these contaminants and evaluated their effect. Figure 7–2 shows a typical sample of dirt collected from insulation surfaces on shipboard. This study resulted in the following conclusions:

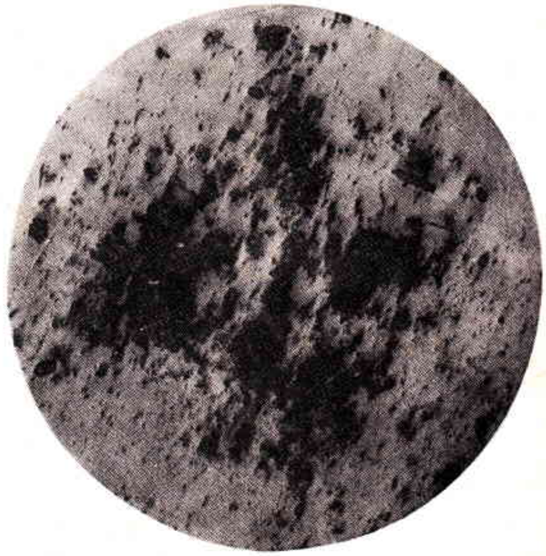


Fig. 7–2. Dirt collected from insulation surfaces on shipboard. (*General Electric Co.*)

1. A liquid must be present to supply adhesion for the solid contaminants which will wet the solid contaminant and also be wet by water.

2. A carbonaceous conducting contaminant may be a serious hazard.

3. Contamination by carbon particles may result in a very low surface breakdown.

4. Ionizable contaminants such as salt may result in surface breakdowns at low voltages with less than 100 percent relative humidity.

This work disclosed that a large number of factors enter into such surface breakdown and that laboratory evaluation is difficult. However, it demonstrated that **surface contamination is a serious problem, which the maintenance man must recognize and combat.**

7-41. *Effect of Acid Soldering Fluxes*

Figure 7-3 shows an excellent example of an operating failure which resulted from insulation contamination with acid flux. This failure occurred on a commutator at operating voltages of less than 50 volts bar to bar. When the commutator was dismantled and tested by checking bar-to-bar insulation resistance, it was found that 70 mica segments out of 300 had far below normal insulation resistance. The normal value was above 10 megohms, whereas that of the contaminated segments was less than 0.1 megohm. Upon applying an overpotential test it was found that the bars with low insulation resistance stood a 200-volt test but failed at 400 volts. On the other hand all segments with normal insulation resistance withstood a 600-volt test and failed at not less than 800 volts. It is important to note that the act of removing the insulation for examination permitted evaporation of some of the moisture, so that more than 200 volts were required to break down those creepage surfaces which failed in operation at less than 50 volts. This is indicative of the hairline differences between test voltages in the range between 50 and 400.

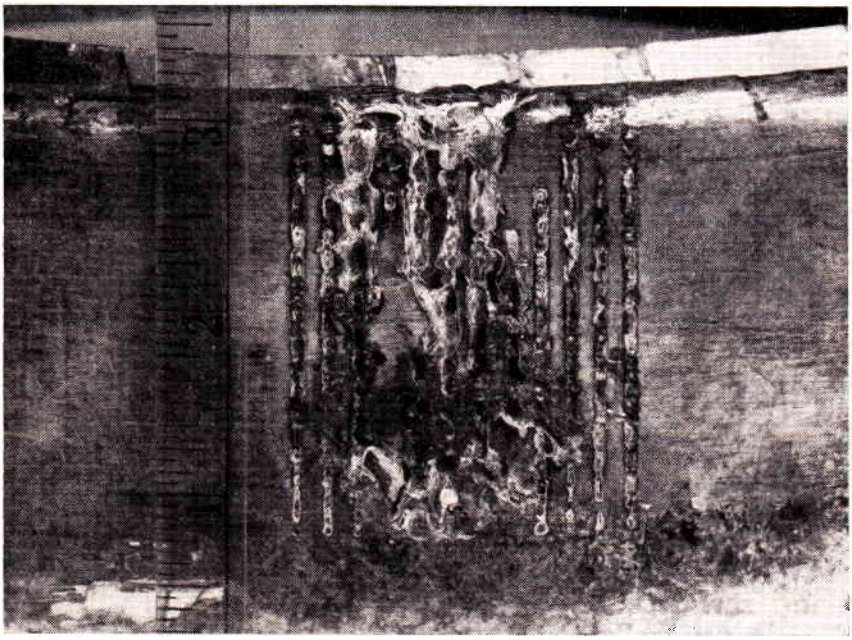


Fig. 7-3. Typical failures of commutator mica due to acid flux. (*Westinghouse Electric Corp.*)

Mica segments were removed from the supports with low insulation resistance and from other supports with uncontaminated mica, small samples of the mica were boiled in distilled water, and the conductivity of the solution determined. It was found that

the conductivity of the water solution was increased by a factor of 10 to 1 owing to the presence of the acid soldering flux contaminant in the mica.

7–42. *Effect of Hand Creams*

Protective hand creams are used quite commonly by workmen applying insulation. The use of these creams is encouraged in varnish-treating rooms, coil-insulating sections, and wire-insulating departments as insurance against dermatitis. Such creams are effective in prevention of skin irritations due to varnish, solvents, and adhesives. However, it should be noted that many of these creams which do not harm the skin contain conducting materials which are corrosive to copper or harmful to insulation. Skin creams and ointments can be classified as follows:

Simple vanishing-cream types which fill the skin pores with soap and facilitate removal of soil when washing after work.

A second type which leaves a thin film of resin or wax on the skin and thus keeps the irritant from direct contact with the skin.

A third type which fills pores and covers the skin with a harmless fat that repels water-soluble irritants and prevents entrance of petroleum oils, greases, and coal-tar derivatives.

A fourth type which contains nonirritant chemicals intended to detoxify the irritants.

Another form which causes inert powders to adhere to the skin, forming a physical barrier against skin irritants.

Tests made on all these classes of materials found that the creams which had soap bases and were alkaline in reaction became conducting at higher humidities. Their use resulted in lowered insulation resistance on materials contaminated by them. Such hand creams were also found to reduce the dielectric breakdown after the test samples had been humidified approximating summer weather conditions. The hand creams found most troublesome were alkaline soap base and the vanishing-cream type. One of these soap-base hand creams was found to make subsequent varnish treatment quite difficult, as streaks of the cream dissolved into the varnish. The cream melted and ran during subsequent baking. The varnish treatment resulted in a very poor film with greatly reduced dielectric strength even when dry.

The satisfactory types of hand creams are those which leave a thin film of resin or wax on the hands which is neutral in reaction. The use of these hand creams is not detrimental to insulation if moderation is practiced. It is important that the hand creams used when handling insulation be approved not only by industrial hygiene authorities but by a responsible insulation engineer.

7–43. *Effect of Germicides*

Figure 7–4 shows a creepage failure of an armature coil. Here a creepage distance of approximately 1 inch failed on a 1-minute high-potential test of 3,000 volts, 60 cycles. This failure was traced to the presence of ionizable germicides in the mold lubricant on the pressing blocks which were used for consolidating this insulation. This emphasizes the need for control of materials used in connection with insulation.

7–44. *Motors Operating in Chemical Atmospheres*

Motors operating in chemical atmospheres require careful attention because of excessive contamination with ionizable compounds especially on the creepage surfaces. Similar contamination may occur on motors in marine service, where they may be subjected to salt spray and subsequent evaporation of the water. Most of the atmospheres

encountered in chemical plants contain high concentrations of ionizable materials which are frequently deposited on windings. Many of these materials have a very high insulation resistance when dry, but when they are humidified, the insulation resistance changes by a tremendous factor. These materials not only form conducting paths across the creepage surfaces but may be deposited in cracks in varnish films and around leads. Unless this contaminating material is washed out and dried and the surface sealed by additional varnish treatments, trouble can be expected. It is important that such ionizable materials be removed in so far as possible before additional varnish treatments are applied; otherwise the ionizable materials will be sealed in where they still represent a major hazard.

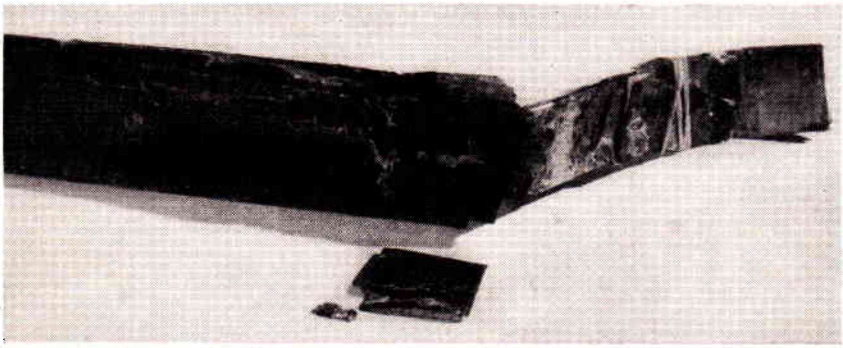


FIG. 7-4. Creepage failure of armature coil due to conducting germicide. (*Westinghouse Electric Corp.*)

8. Summary

8-1. GENERAL INSULATION CHARACTERISTICS

Insulators are high-resistance conductors which guide the flow of electricity into useful channels.

All solid insulations conduct electricity and therefore have insulation resistance. Insulation resistance is subject to wide variation in absolute value as a result of changes in temperature, moisture content, and humidity on creepage surfaces. Insulation resistance also varies with test voltage and time of voltage application.

Dielectric absorption is the ability of insulation to absorb energy as a capacitor.

Dielectric constant is an index of the ability of a dielectric to absorb an energy charge.

Power factor is a measure of the relative dielectric loss in an insulator and the internal heating under voltage stress.

Dielectric strength is a measure of the ability of an insulation to withstand voltage stress. Dielectric strength varies with rate and time of voltage application, frequency of voltage, atmospheric conditions, temperature, thickness, and electrode shape.

The dielectric breakdown of air is used as a reference for the measurement of very high voltages. The breakdown of air is preceded by a corona discharge caused by the movement of electrons and the resultant ionization of the air adjacent to the electrodes.

Dielectric barrier effect is produced only by solid insulation. Where insulation is porous, the effective creepage spacing dielectric level is usually less than the breakdown of the intervening air.

Breakdown of solid insulation is explained by three theories. The thermal theory explains breakdown as runaway current resulting from thermal instability produced by internal heating. The ionic theory explains breakdown as produced by ionization and concentrated currents. The disruptive theory attributes dielectric breakdown to physical rupture with the destruction of molecular and other bonds in the dielectric. No one of these theories can explain all types of breakdown.

The breakdown of solid insulation is necessarily dependent upon the time of voltage application. Any statement of dielectric strength must include the time factor.

A-c and d-c voltages have different effects on insulation, and there is no recognized relationship between them in so far as dielectric breakdown level of solid insulations.

In many cases turns of a coil or low-voltage circuits do not require positive

dielectric barrier insulation. In such cases spacing insulation through porous materials or over creepage surfaces may be adequate (especially when operating under dry conditions).

Two insulating materials in series do not necessarily divide the voltage across them in proportion to their thickness. The voltage distribution depends upon the dielectric constants as well as the thickness of the two materials.

8-2. VARIABILITY AND STATISTICAL ANALYSIS

All insulation properties vary widely in absolute value even on apparently identical samples. Statistical analysis methods enable determination of average values and prediction of the extremes of the range which can be expected on normal materials. Average alone may be confusing. Average values plus a knowledge of the inherent variability and probable range of the data give a much clearer picture.

8-3. THERMAL AGING AND INSULATION LIFE

Thermal aging is a very important factor in establishing insulation life. All known insulations employed in electric machinery are subject to thermal degradation and aging. Insulation does not fail immediately at any critical temperature but fails by gradual mechanical deterioration at elevated temperatures. Present concepts of insulation aging are based on the rule of thumb that thermal life of insulation halves for each temperature increment (generally 10 degrees C). There is no absolute criterion for insulation-life end point. Insulation life is a variable determined by many causes once thermal aging has made it vulnerable. Most electrical failures are attributable to insulation. Generally actual failures of insulation are produced after thermal aging by one of the following immediate causes:

1. Surge voltages
2. Mechanical damage
3. Dirt, oil, and chemical contaminants
4. Corona deterioration
5. Moisture absorption

8-4. THERMAL CONDUCTIVITY

The ability of windings to dissipate heat has an important effect on the temperature attained within, which in turn affects thermal aging. High thermal conductivity is desirable in most insulations. High heat storage is desirable on intermittently rated apparatus but is not so important on continuously loaded equipment.

8-5. ARC RESISTANCE

Materials exposed to arcs frequently track or produce conducting carbonized paths over their surfaces. The arc resistance of a material is of considerable importance where it may be subjected to flashover during operation.

8-6. CORONA

Corona is an electrical discharge occurring in a gas when the critical voltage of the gas is exceeded. Corona may occur between either bare conductors or insulated conductors. Corona adjacent to insulation may damage the organic components and corrode metal. There is a wide difference in the effect of corona on various insulations.

8-7. MOISTURE EFFECTS

Moisture affects insulation by absorption into the pores or by wetting the surfaces. Both actions increase the conductivity of most insulators by a tremendous factor. Treatment of insulation to fill the voids and coat the surfaces may greatly improve this con-

dition but cannot completely overcome it. There is no known insulating barrier for windings which is completely impervious to moisture penetration.

Many insulation failures are attributable to the presence of moisture and associated effects which lower the dielectric strength.

8-8. CLASSES OF INSULATION AND PROPERTIES OF MATERIALS

Apparatus is usually insulated by one or all of three methods, consisting of spacing through an insulating fluid, creepage over insulating surfaces (or through porous insulation), and solid dielectric barriers. The dielectric strength of solid insulation is as much dependent upon the technique of fabrication as it is on the inherent characteristics of the component materials. Seemingly similar materials may differ in breakdown strength by a factor of 10, even when identical component materials are used, because of differences in technique of fabrication.

Electric insulating materials are defined as those offering very high resistance to the flow of current so they can be used to direct and guide current along conductors. The selection as well as the application of insulation is generally considered an art rather than a science, and insulation systems are often designed by cut-and-try methods. Insulation engineers are attempting to rationalize insulation practices in order to promote a more scientific approach which will lead to a better understanding of insulation problems. Yardsticks for insulating materials must be understood, as materials are often tested under conditions differing from actual use. Furthermore, many of the insulating properties of materials suffer from abuse during handling. The user is interested in the properties of the materials in final form on the winding.

The following properties of insulation should be considered in its selection and use:

Physical properties
- Flexibility
- Abrasion resistance
- Tear strength
- Shear strength
- Flexural strength
- Tensile strength
- Bond strength

Electrical properties
- Dielectric strength
- Insulation resistivity
- Power factor
- Dielectric constant
- Corona resistance
- Arc resistance
- Moisture resistance

Chemical properties
- Resistance to oils and solvents
- Resistance to weak acids and alkalies
- Effect of ozone
- Inflammability
- Thermal stability

8-9. TEMPERATURE CLASSIFICATION

Industry as well as Navy standards classify insulation as:

Class O, organic insulation, unvarnished and unimpregnated.

Class A, organic insulation, varnish-treated or immersed in a liquid dielectric.

Class B, inorganic materials in built-up form with organic binding substances.

Class H, inorganic materials in built-up form with silicone bonds.

Class C, entirely inorganic insulation.

8-10. BASIC INSULATING MATERIALS

There are several basic kinds of insulating materials each of which can be fabricated into a wide variety of composite insulating structures. A brief review of the more im-

portant basic materials and their important characteristics offers an insight into the reasons for the design of insulation systems.

The reaction of the basic insulation constituents to moisture is probably the most important and least understood phenomenon. Moisture affects insulation by absorption into the pores and by wetting of the insulation surfaces, rendering it relatively conducting. There are no insulations which are completely unaffected by moisture, either by absorption into the volume or by collection on the creepage surfaces. There is a vast difference in basic materials used for electrical insulation. The "thirsty-fiber" materials such as **cellulose** and **asbestos** are more sensitive to moisture than the inorganic materials such as **fiber glass** and **mica.** Nearly all forms of basic insulating materials are improved in moisture resistance by varnish treatment. In every case the development of the latent moisture-resistance properties to a high level depends largely on the manner in which the materials are processed as well as the characteristics of the resin chosen for the treatment. The inorganic constituents such as mica and fiber glass are thermally and chemically inert and therefore resistant to most of the contaminating and aging influences experienced in electrical winding. Their limits are largely physical. It is the selection of the resin treatment which is of the utmost importance in determining the final level of insulation obtained.

Plastics and rubbers are largely resinous materials and possess inherent resistance to moisture, but they generally are not chemically stable at high temperatures.

8–11. *Cellulose*

Cellulose products are the most largely used form of insulation. When properly impregnated, these organic materials are excellent insulation at **low** operating temperatures. They have disadvantages such as moisture sensitivity and poor thermal stability, and they require impregnation to obtain good electrical properties. Important advantages are physical strength, ease of fabrication, adaptability to commercial processes, and low cost.

8–12. *Asbestos*

Asbestos is an inorganic fibrous material for use at high temperatures. It is sensitive to moisture and requires impregnation to develop dielectric strength greater than the equivalent spacing.

8–13. *Fiber Glass*

Fiber glass is a newcomer to the insulation field which has outstanding thermal endurance, excellent moisture resistance, good chemical resistance, and great physical strength. Its advent greatly accelerated the development of class H insulation as well as stimulated the use of class B insulation because of better space factor and greater physical strength than asbestos. Fiber-glass fabrics are not dielectric barriers and offer only spacing insulation unless they are varnish-treated.

8–14. *Mica*

Mica is an inorganic flake material possessing great dielectric strength, low dielectric loss, and high electrical resistivity. Its thermal stability is outstanding. It is chemically inert, being unaffected by water, conventional solvents, and most acids and alkalies. Mica is of particular interest because it possesses inherent dielectric barrier action not possessed by any other material. Mica is very largely used throughout the electrical industry wherever high dielectric strength is required, especially where the

insulation is subjected to high temperature or corona.

8–15. *Varnish Composition*

Early varnishes were made from natural oils or resins. Modern varnishes are made from synthetic resins, which may be modified with the higher grade natural oils. Alkyds, phenolics, melamines, and silicones are examples of synthetic resins.

Most air-drying varnishes, such as spirit varnishes, dry by solvent evaporation and have insignificant insulating properties. Baking varnishes heat-cure by oxidation and polymerization and present a better physical and chemical barrier to the contaminants which may affect insulation. Natural resins must be used as they occur (may vary in properties and contain impurities) and will vary from lot to lot in properties and usability. Synthetic resins have the advantage of uniformity of composition and performance and can be "tailor-made" for a specific application. Silicone resins constitute an important group of synthetic resin varnishes that have made valuable contributions to better thermal life of insulation and windings.

8–16. *Selection of Varnish*

There are two distinct groups of varnishes used on coils and windings, namely, organic varnishes and silicone (semiinorganic) varnishes.

1. Organic varnishes are graded as follows:
Grade BA, black, air-drying, insulating
Grade BB, black, baking, insulating
Grade CA, clear, air-drying, insulating
Grade CB, clear, baking, insulating
Grade CF, clear, finishing

These organic varnishes are further described as type N for Navy use and type M for manufacturers' use in their factories or repair shops.

2. Silicone or semiinorganic varnishes are graded as grade LTB, low-temperature baking, and grade HTB, high-temperature baking.

Note. There are no air-dry varnishes of the silicone resin family.

Requirements for all varnishes include significant performance characteristics such as the following:

1. Varnish must preserve the initial dielectric strength of the insulation by exclusion of deleterious substances.
2. Varnish must be chemically stable to moisture.
3. Varnish must be chemically stable at the operating temperature for the insulation class.
4. Varnish film must withstand freshwater immersion.
5. Hardness of varnish film must be acceptable.
6. Insulation resistance of varnish film must be high after acidproofness and seawaterproofness tests.
7. Varnish film must not be affected seriously by transformer oils.
8. Varnish solutions must not corrode copper, brass, or steel.
9. Varnish must be capable of application in continuous films.
10. Hiding power of black varnishes must be good.
11. Varnish film must have at least the minimum flexibility specified for heat endurance.
12. Varnish film must have minimum acceptable dielectric strength under wet and dry tests.

8–17. *Solvents*

Varnish solvent brings resins or gums into fluid state to permit easy application as

uniform film. A thinner, or diluent, used to dilute a varnish containing a solvent may not be a true solvent. Solvent characteristics include:

1. Solvency power.
2. Volatility.
3. Toxicity.
4. Inflammability.
5. Stability.
6. Specific gravity.
7. Refractive index.
8. Acidity.

8–18. *Plastics*

Plastics can be defined as nonmetallic materials capable of being molded or fabricated into sheets, tubes, rods, filaments, or complex forms. Many plastics employ organic resins similar to those used for varnishes. Natural resins have been used in the plastics industry, such as shellac, bituminous resins, and rubber. The development of phenol formaldehyde marked the beginning of the modern plastics industry. There are two classes of plastics depending on their reaction to heat. Resins which soften but experience no chemical change when heated are thermoplastic and can be resoftened again and again. Resins which undergo a chemical change when heated are thermosetting and cannot have their form altered by further heating, except to destruction. Most resins are not used alone in the plastics industry but are extended by fillers. Frequently resins are modified in their physical properties by the addition of plasticizers in order to make them softer and more flexible.

8–19. *Rubber and Rubbery Materials*

Rubber is a natural plastic derived from the sap of a tropical tree. When vulcanized by heating with sulphur, rubber attains excellent elasticity, high tensile strength, durability, and resistance to moisture and solvents and is insensitive to moderate temperature changes. There are many rubberlike materials which are generally classified as synthetic rubbers and elastomers. These vary widely in chemical composition as well as physical and electrical properties.

8–20. INSULATING FABRICS

A wide variety of insulating fabrics is employed for electrical insulation. In this category are included cotton, linen, silk, synthetic fiber, fiber-glass, and asbestos fabrics as basic materials. All are available either in untreated form or with varnish treatment. Cotton, linen, silk, and synthetic fiber fabrics are generally used in low-temperature applications as class O and A materials. Fiber-glass and asbestos fabrics can be either class B or class H depending upon the type of impregnant employed. Fabrics are available in several forms. Tapes and cloths are the more common, but tubing and sleeving must also be considered as fabrics. Varnished tubing and saturated sleeving are important forms of fabric-type insulation that have wide usage.

8–21. *Papers and Pressboard*

Insulating papers and pressboard are made up of chemically treated fibers which are partially gelatinized in the untreated form. They are all sensitive to moisture but when varnish-impregnated have good dielectric properties as well as excellent physical properties. Many types of paper are very tough, strong, and dense and withstand physical abuse well.

8–22. *Mica Products*

Mica products are all made from mica splittings which are built up in multiple

layers. Tapes and wrappers are always built on a backing of paper or fabric. Mica plate is generally built without backing. Splittings are laid either by hand or by machine depending on thickness and dielectric requirements. A wide variety of bonds is used for various mica products. The electrical, physical, and chemical properties of a mica product depend upon the size of the splittings employed, the manner in which the splittings are laid and overlapped, the nature of the bond employed, the quantity of the bond, and the nature of the backing, if any.

8–23. *Laminated Thermosetting Products*

Thermoset laminates consist of fibrous sheet materials, such as paper or fabric, impregnated or coated with a resin binder and consolidated under high pressure into hard, solid products with high mechanical strength. Most laminated products are bonded with phenolic resins, although melamine resins, urea resins, and silicone resins are now being more widely used. Laminated products include sheet materials, rolled tubes, molded rods and shapes, and machined rods.

8–24. *Magnet Wire*

Copper is necessarily associated with insulation for windings, as the main objective of insulation is to confine the electric current to conductors. Copper wire is manufactured in standard gauge sizes (AWG). In this system consecutive wire sizes have a ratio of 1.26 in area—the larger the number, the smaller the wire. Standard wire sizes always refer to copper diameter. Insulated wire sizes depend upon the type of insulation, as some insulations are much thicker than others. The space factor for magnet wire is defined as the ratio of the area of the copper conductor to the area of the rectangle circumscribed about the over-all dimensions of the completed wire. For round magnet wires:

$$s = \frac{\pi}{4}\left(\frac{w}{d}\right)^2 \times 100$$

where s = space factor, percent.
w = diameter of bare conductor, mils.
d = over-all diameter of insulated wire.

Dielectric strength data on insulated wire should be considered as comparative only. Wire insulation should be selected for physical strength, thermal stability, space factor, and ability to withstand winding abuse rather than dielectric strength as determined by laboratory test.

8–25. SELECTION OF MATERIALS

Insulation confines current to the useful channels, through conductors, without significant leakage into undesired paths. Primary electrical requisites of insulation are high dielectric strength, high electrical resistivity, low dielectric loss, and low moisture absorption. Physical properties of insulation are also of major significance in their selection. Insulation must withstand severe mechanical abuse during manufacturing plus normal mechanical stress during operation. Mechanical requirements are tensile strength, tear strength, bond strength, and ability to withstand bending without loss of important electrical properties. Chemical properties are of great importance also, as insulation must resist damage by oils, solvents, weak acids, and alkalies. Low inflammability is desirable. Resistance to ozone attack is required for insulation operating at more than 6,000 volts. Thermal stability is the most important chemical property for determining insulation life.

Selection of insulating materials for specific applications involves compromise. Desirable properties should be summarized and

reviewed in the order of importance, and materials selected which best fill the specific needs of each application.

8–26. TYPES OF WINDINGS

1. Random-wound coils are used on smaller motors, especially those for low-voltage applications.

2. Form-wound coils are used for medium-sized and large motors, especially those of higher voltage operation.

8–27. CLASS H WINDINGS

Class H windings for high-temperature duty differ significantly from conventional types of insulation. Organic insulation components must be avoided in class H coils, as their presence will result in destruction of the varnish film during baking or operation.

8–28. COIL CONSTRUCTION

Insulation should be considered as subdivided into three groups: (1) conductor insulation, (2) ground insulation, (3) binder or physical-support insulation.

1. Conductor insulation usually furnishes positive separation and is not relied upon for more than spacing insulation.

2. Ground insulation is the major insulation and should provide very positive dielectric barrier action. Ground insulation consisting of slot armor or wrapper must have high dielectric strength, good moisture resistance, thermal endurance for the permissible operating temperature, and ability to withstand winding abuse.

3. Binder tapes are for structural and finishing purposes. They are more for mechanical protection and as a base for varnish treatment than actual insulation.

8–29. TURN INSULATION

Turn insulation is generally provided by standard covered wire, although on larger apparatus mica tape may be applied to the conductors. On edge-wound coils paper is commonly used for turn separation (organic paper for class A and asbestos paper for the higher temperature classes).

8–30. FIELD COILS

Field coils can be described as open or cell-type and mummified coils. Cell-type coils have exposed uninsulated surfaces scrubbed by ventilating gas and are insulated with solid insulation only where adjacent to the frame or poles. Mummified coils are completely encased with solid insulation to provide coverage over all surfaces. This construction is used under conditions of extreme moisture and dirt or where space is limited.

8–31. HIGH–VOLTAGE ARMATURE COILS

Large high-voltage motor and generator armature coils use stranded conductors separated by insulation to reduce eddy-current loss. On some machines the strands are transposed both within the slot and from slot to slot. Strand insulation usually consists of standard wire covering. The groups of strands that form a turn or conductor group are insulated with mica tape. Extremely long coils or coils which are difficult to wind are frequently made in halves for ease of winding.

8–32. INSULATION SYMBOLS

The NEMA renewal-part coil-indexing system describes the class of insulation used in each part of the coil. The standard AIEE and ASA insulation class nomenclature is used. The first letter indicates turn

insulation, the second letter ground insulation, and the third letter binder insulation. Letter N indicates none, and U indicates untreated asbestos. The letter X refers to slot size, and V indicates vacuum impregnation.

8–33. COMMUTATOR CONSTRUCTION

Commutators are the heart of d-c machines. On small machines they are simple and present minor physical and electrical problems. On large machines, especially those for high-speed operation, the insulation must act as a system of springs which performs important mechanical functions as well as fulfilling electrical requirements. Unless proper materials are used, with adequate design and careful manufacture, commutator trouble can be expected. Commutators are usually seasoned in order to stabilize the mica bonds. The larger the commutator, the more important this seasoning process is. Mica V rings provide the dielectric barrier between commutator segments and the grounded parts. Mica V-ring extensions in commutators must be protected by insulating bands with suitable resin treatment. These creepage extensions frequently require cleaning and re-treatment. Mica segments provide creepage or separating insulation between the copper segments.

8–34. SLIP RINGS

Slip rings on a-c machinery bring electrical connections from the rotor to external circuits. These are much simpler than commutators used on d-c machines. More complicated problems are encountered on larger slip rings where the contact rings may be shrunk onto mica-insulated steel bushings with considerable pressure on the mica. Creepage surfaces on collector rings require similar protection to mica V-ring extensions on commutators.

8–35. MACHINE CONSTRUCTION

Motors and generators of similar size are frequently indistinguishable mechanically. There is far more difference between large and small motors, depending on whether they are mass-produced or tailor-made, than between motors and generators.

D-c machines are all somewhat similar in appearance regardless of size. All contain separate stationary field coils and rotating armatures equipped with commutators.

Most a-c machines have stationary armature windings usually called stator windings. A-c machines differ more widely than d-c machines and can be subdivided into several groups. Induction motors differ more as a function of size, the smaller ones employing quite different coil construction from the larger ones. Small mass-produced induction motors are made with random windings, whereas the larger sizes are usually made with preformed and preinsulated coils.

Large motors and generators for low-speed operation are often salient-pole synchronous machines. Armature coils are generally preformed and preinsulated. Field coils are often wound on poles or on forms. Both types of field coils are insulated by cells and washers.

The turbine generator is a specialized design of high-speed generator directly connected to a steam turbine. Stator windings are somewhat similar to other large a-c stator windings but are usually much longer. The major distinguishing characteristic of the turbine generator is the rotating field. The field coils are embedded in the slotted rotor and must have special mechanical support because of high operating speeds.

8-36. WINDING COILS INTO MACHINES

The importance of careful workmanship by trained personnel cannot be overemphasized. A great deal of damage can occur during the winding of coils into slots or assembly. Skill in winding requires training and understanding of the problem. Differences in the technique and skill of winders are not always apparent. The final closing of the last throw of a winding offers the greatest opportunity for damage to insulation.

8-37. ALLOWED CREEPAGE AND STRIKING DISTANCES

Space allowances for creepage over insulating surfaces and striking through intervening gas vary widely with size and importance of the apparatus as well as the conditions under which machines operate. High factors of safety are usually allowed because of the tremendous reduction in effective spacing resulting from contamination by moisture, dirt, and conducting chemicals.

8-38. WINDING PROCEDURES

All winding procedures require very careful workmanship. Random windings are designed for low cost and ease of installation. Preformed, preinsulated coils are designed for larger, higher cost apparatus where space, output, and reliability predominate over economic considerations.

8-39. CROSS CONNECTIONS ON D-C ARMATURES

Parallel-wound d-c armatures frequently have cross connections between commutator segments of the same polarity. These cross connections have individual turn insulation and are insulated from ground as a group as well as between top and bottom layers.

8-40. CONNECTIONS FOR STATOR COILS

Connections between stator coils are quite important, as they may be a major source of trouble unless properly handled. The type of connection and the process (soldering, brazing, or clamping) for connecting used will depend upon the insulation class as will the type of insulation applied to cover these connections.

8-41. WIRING AROUND FRAME

On d-c motors and generators there are usually a number of circuits which require connection through the wiring around frame. Heavy straps are supported in air between coils and have spacing insulation through air. Other circuits are frequently connected by conventional cable or specially insulated connectors.

8-42. SUPPORT FOR ARMATURE COILS

Large a-c machines may encounter magnetic forces which would distort the coil and windings unless supported. Adequate support and bracing are imperative.

8-43. BANDING D-C ARMATURE COILS

Rotating armature coils on d-c machines must be supported to overcome centrifugal forces. Coils are generally banded down against insulated support rings at both front and rear. These bands are usually not grounded and must therefore have full-voltage insulation to the coil ends.

8-44. SUPPORTING ROTATING FIELD COILS

Rotating field coils must be secured against centrifugal forces either by use of

thermosetting compounds between turns of the coils or by blocking between coils.

8-45. APPLICATION OF WEDGES AND SLOT FILLERS

Material used for wedges and slot fillers depends upon insulation class. Class of insulation should generally correspond to coil-insulation class. All coils should be tight when wedged at room temperature. Proper tools must be used to avoid mechanical damage to coils during wedging. Slot wedges and fillers should be made of nonshrinking materials.

8-46. PUTTIES AND CEMENTS

Dead-air pockets within solid insulation and around connectors should be filled with putties and cements. This improves heat dissipation, minimizes breathing, and excludes dirt. It also facilitates neat covering of connections with tape.

8-47. CORONA IN HIGH-VOLTAGE WINDING

Corona may occur in high-voltage windings when gas adjacent to solid insulation is stressed beyond the critical voltage. Corona is usually not a problem in machines operating below 6,000 volts. Slot corona may exist in tiny voids between solid insulation and core punchings. Slot corona can be eliminated by application of a conducting sheath to the solid insulation within the core if the sheath is grounded to the core. End-winding corona occurs where coils leave the slots and between adjacent coils. End-winding corona can be suppressed by the application of a high-resistance semiconducting sheath which extends from the conducting sheath on the slot part into the end windings.

8-48. REMOVAL OF OLD INSULATION

When rewinding a machine old insulation must be removed without damage to core and the insulation between laminations. Solvents used must not attack lamination insulation. Overheating will damage most lamination insulation. Mechanical stripping of coils and insulation is the best method of preparing cores for rewinding.

8-49. BEARING INSULATION

Large a-c machines may have stray currents which damage bearings. Low-voltage insulation at one end of machine is used to interrupt the circuit formed by shaft, bearings, and frame.

8-50. SOLDERING AND BRAZING

The melting temperature of solder used in making connections must be coordinated with class of insulation and operating temperature of the machine. A small percentage of lead contaminant may seriously affect the melting point of solder. Only neutral fluxes should be used adjacent to insulation. Acid fluxes contain ionizable materials which are harmful to insulation. Brazing is frequently used for class H insulation instead of soldering, although satisfactory high-temperature solders are available.

8-51. VARNISH TREATMENT

Treating compounds and varnishes are of outstanding importance in electric machinery. Only the very lowest temperature class of electrical insulation (O) does not require varnish treatment. All other classes of insulation require impregnation and surface treatment with varnishes (or other impregnants) to fill their interstices and fortify their surfaces against the inroads of various contaminants. Shipboard apparatus especially needs varnish treatment because of

4. Measure specific gravity, and correct to common reference temperature.

5. Corrected viscosity and specific-gravity values indicate condition of varnish. Rapid increase in viscosity for a particular gravity indicates serious aging of varnish.

8–56. VARNISH VISCOSITY

Viscosity is expressed as the time for a given volume to flow through a specific orifice. Approximate viscosity measurements can be made with a ½-pint-capacity can with a hole ⅛ inch in diameter. Calibrate with water by filling the can and observing the seconds required for water to run out. Water has 7-seconds approximate viscosity by Demmler No. 1 and Zahn No. 2 cups and approximately 5 seconds by Dow Corning No. 2 cup. Determine the ratio for the particular cup, and use the ratio for measuring varnish viscosity when emergency methods are necessary.

8–57. CLEANING, DRYING, REPAIRING, AND VARNISHING

Cleaning is an important part of maintenance. Dust, dirt, and foreign matter block ventilation, reduce heat dissipation, and may contaminate insulation surfaces. There are several acceptable methods of cleaning as follows:

1. Wiping is effective in removing dirt on accessible parts of machine only.

2. Compressed air is effective in removing dirt from inaccessible locations of machines. Clean, dry air should be used. The pressure should not be excessive for the particular class of equipment.

3. Cleaning by suction is preferable to compressed air, since it removes the dirt from the machine.

4. Cleaning by use of solvents should be avoided as far as practicable. Solvent cleaning is effective, but all solvents have some objectionable features. Most solvents are either toxic or a fire hazard, and the one selected will depend upon application conditions. It is nearly always necessary to compromise in solvent selection. Do not use alcohol, gasoline, or benzine for cleaning.

5. Clean, fresh water (preferably warm) may also be used for cleaning.

8–58. INSTRUCTIONS FOR REVARNISHING

Never apply varnish until the winding or insulation has been thoroughly cleaned. Varnishes are to be applied only where a useful purpose is served. Unnecessary varnishing is dangerous. The most satisfactory moisture-resisting coatings are obtained by dip-coating coils and apparatus in suitable baking varnish. Spray coats are inferior. Air-dried varnishes are less resistant to moisture than baking varnishes.

For general Navy use on class A and class B windings, clear baking (CB) grade varnishes are preferred. Varnish should be used at a temperature of 25 to 35 C with viscosity maintained at 50 to 100 seconds corrected to 25 C (Zahn No. 2 cup or Demmler No. 1 cup). After equipment has been thoroughly cleaned, dried, and cooled to room temperature, it should be dipped so that the winding is immersed in the varnish. Immerse 15 minutes for the first dip and 5 minutes for each additional coat. Do not immerse the commutator. Bake apparatus at 130 to 135 C for 6 hours on preliminary dips and 15 hours after last dip. Longer baking time may be necessary on larger equipment.

On class H windings silicone varnishes (LTB or HTB) must be used. Varnish should be used at a temperature of 25 to 35 C with viscosity maintained at 30 to 48 seconds (corrected to 25 C) as measured by

Dow Corning No. 2 cup. Dipping procedure corresponds to that for organic varnishes, but baking requires higher temperatures as follows:

Varnish grade	*Baking temperature*
LTB	80–200 C (in steps)
HTB	80–250 C (in steps)

Air-dried varnishes should be used only in certain special cases. Varnish for spraying should have viscosity 25 to 60 seconds at 25 C (by No. 2 Zahn, No. 1 Demmler, or No. 4 Ford Cup). Equipment to be sprayed must be within a temperature range of 20 to 25 C. Varnish to be sprayed must be clean and free from skins.

Application of varnish by brushing should be limited to places not reached satisfactorily by spraying or to touching up spots of limited area.

8–59. DRYING INSULATION

Moisture absorbed by insulation or on its surfaces may result in electrical failures. Dielectric strength and insulation resistance are reduced significantly and permanent damage may result if the moisture is not properly removed by drying. Drying is accomplished by heat and the circulation of dry air or the application of vacuum. Heat may be applied internally by current or externally by one of a number of methods.

Do's

1. Heat gradually.
2. Provide ample circulation of dry air.
3. Heat steadily.
4. Observe temperature of apparatus during heating.
5. Observe insulation resistance of windings periodically.

Don'ts

1. Don't hurry the drying process.
2. Don't overheat the apparatus.
3. Don't interrupt the heating.
4. Don't permit drying to produce fire hazards.
5. Don't restrict removal of moisture-laden air.

8–60. *Oven Drying*

Ovens are usually the most convenient and easily provided facility for drying. Crude ovens are satisfactory if the temperatures provided are not excessive.

8–61. *Vacuum Drying*

The rate of removal of moisture can be accelerated by drying in a vacuum, as this lowers the boiling point of the water. Vacuum drying permits use of lower temperatures with less damage to the insulation from thermal aging. Excessive vacuum may be damaging, as too rapid evaporation of moisture may rupture insulation.

8–62. *Drying with Electric Heaters*

Electric heaters or infrared lamps provide a satisfactory source of heat and are frequently convenient for heating apparatus in place. Care must be taken to avoid overheating of the apparatus in spots, especially on the insulation surfaces exposed to radiant heating.

8–63. *Drying with Circulating Current*

Very large machines are sometimes difficult to dry with external heat. Circulation of current through the windings from an external low-voltage source will frequently overcome this limitation. Some types of machines can be dried by operating them under short-circuit conditions at reduced speed with partial field.

8–64. *Insulation Resistance during Drying*

Readings of insulation resistance provide a useful indication of the progress of drying.

Usually the insulation resistance will drop as the machine warms up. It will reach a minimum and then start to rise rapidly at first as the insulation dries and then more slowly as the drying progresses. When all the excess moisture is driven out, the insulation resistance will no longer increase with time of drying.

8-65. *Check on Salt Removal*

Windings that have been wet with salt water are extremely sensitive to ambient humidity conditions. If the insulation resistance of a reconditioned machine falls rapidly when standing cold in a humid atmosphere, this indicates that the salt has not been completely removed.

8-66. SUMMARY OF GENERAL INSTRUCTIONS ON VARNISHING

Do's

1. Apply varnish only when it serves a useful purpose.
2. Apply dipped coats in preference to spray coats.
3. Use baking varnishes in preference to air-drying varnishes.
4. Use Navy-approved type N or M according to where used. Specification JAN-V-1137 grade CB is preferred on classes A and B insulated windings.
5. Use silicone varnish on all class H insulated windings.
6. Control the viscosity of the varnish in the dipping tank in the following ranges:

Varnish grade	Viscosity range, sec at 25 C	By viscosimeter type
CB	50–100	Zahn No. 2 Demmler No. 1
LTB HTB	30–48	Dow Corning No. 2

Don'ts

1. Don't apply varnish to a winding until it has been thoroughly cleaned and dried.
2. Don't apply unnecessary varnish coats which will interfere with heat dissipation.
3. Don't apply sprayed varnish coats when apparatus can be dipped.
4. Don't use air-drying varnishes when baking varnishes can be used.
5. Don't mix different grades of varnish.
6. Don't use organic varnish on class H temperature windings.

Note. There are exceptions where special instructions are issued; for example, class H magnet wire may be used with organic varnish for class B insulated machines.

8-67. DIPPING INSTRUCTIONS

Do's

1. Immerse apparatus in varnish until bubbling ceases.
2. Immerse complete winding or rotate so winding is immersed several times completely.
3. Drain until dripping ceases.
4. Clean journals and metal fits with solvent before baking.
5. Bake apparatus treated with organic varnish in forced draft oven at 130 to 135 C. Baking temperatures for silicone, class H, apparatus range from 80 to 200 C for LTB grade varnish and from 80 to 250 C for HTB grade varnish.
6. Bake armatures in vertical position if possible.

Don'ts

1. Don't dip apparatus while hot.
2. Don't immerse commutator.
3. Don't underbake as to time or temperature.
4. Don't permit excessive varnish accumulation on coils or in vent ducts.

8-68. SPRAYING AIR-DRYING VARNISHES

Air-drying varnishes are used primarily for appearance. They may be sprayed with conventional spraying equipment. Two coats are usually adequate. Not more than three coats should be applied at a time. Air-drying varnishes dry by solvent evaporation and surface oxidation. Therefore drying time varies with atmospheric conditions as well as varnish characteristics. There are no air-dry varnishes of the silicone type.

Do's

1. Provide adequate ventilation.
2. Wear a respirator and goggles when spraying varnish.
3. Keep spray guns clean and in good condition.
4. Apply two or three coats.

Don'ts

1. Don't spray near open flame.
2. Don't spray varnish at low temperatures or work at low temperatures.
3. Don't apply excessively thick coats.
4. Don't apply too many coats.
5. Don't use air-dry varnish on silicone-insulated equipment.

8-69. REHABILITATION OF INSULATION DAMAGED BY SEA WATER

Do's

1. Dismantle immediately.
2. Clean promptly.
3. Wash out with fresh water by hose or submersion.
4. Remove rinse water promptly.
5. Blow out with compressed air.
6. Clean with recommended solvents.
7. Clean with approved cleaning compounds and detergents.
8. Use cleaning and rinse water of proper temperature.

Don'ts

1. Don't use excessive air pressure when blowing out.
2. Don't use improper solvents which may be inflammable, explosive, or toxic.
3. Don't use highly alkaline compounds which are injurious to insulation.
4. Don't use brackish water.

8-70. TREATMENT OF APPARATUS FOR TROPICAL CLIMATES

Tropical climates subject insulation to severe conditions that promote the growth of fungi, bacteria, and other minute organisms. These grow on insulation under severe humidification only in warm climates. A food supply is essential to the growth of such organisms, but organic insulations and natural oils and resins provide excellent food supplies. Varnish containing poison is temporarily effective in controlling the growth of these organisms when such varnish is applied over standard varnish treatment. Poison must migrate to the surface to be effective and is soon dissipated. Inorganic insulations are not food, and synthetic resins are not assimilated by the organisms.

Class A insulation should not be used in tropical climates. Oleoresinous varnishes should be avoided. Classes B and H insulation are suitable for tropical service.

Where severe moisture conditions are encountered, extra coats of varnish are advisable as an added precaution.

8-71. PROTECTION OF APPARATUS DURING SHIPMENT AND STORAGE

Insulations and varnishes are susceptible to moisture, and reasonable precautions must be exercised to protect these vital parts of electric apparatus during shipment and storage. Previous concepts of packag-

ing and protecting apparatus were erroneous as proved by experience during World War II. Only two methods of protecting the insulation of equipment are acceptable:

1. Completely seal within moisture-vapor barrier and desiccate the space within.
2. Protect equipment from direct rain and snow, but allow adequate ventilation for natural convection.

Don't cover equipment closely with tarpaulin. This is the worst thing that can be done, making a sweat box out of the enclosure.

Don't open electrical equipment which is sealed in a moisture-vapor barrier until just before it is to be used.

8-72. STORAGE AND CARE OF COILS AND INSULATING MATERIALS

Insulating materials should be stored in original containers if sealed. The ideal storeroom should have good ventilation with temperature controlled at 60 to 70 F and 40 to 50 percent relative humidity. If this is not attainable, the room should be well ventilated in summer months and heated in winter. Thermal cycling must be avoided which would result in the air temperature reaching the dew point.

8-73. DIELECTRIC TESTING

Dielectric strength of insulating materials is determined by two kinds of tests:

1. Short-time test (frequently called rapid rise) with voltage increasing at a uniform rate until breakdown results.
2. Step-by-step test where the voltage is increased in steps, each of which is held for a predetermined time, usually for 1 minute, until the insulation fails.

8-74. THERMAL-CONDUCTIVITY TESTS

These tests determine the rate of heat flow through insulation under controlled temperature conditions at a steady state.

8-75. INSULATION-RESISTANCE TESTS

Such tests are made to determine the volume insulation resistance and surface resistance of insulating materials.

8-76. POWER-FACTOR TESTS

These tests determine the ratio of the energy loss in a dielectric to the volt-ampere input. They are a measure of the dielectric loss and internal heating of the insulation.

8-77. ARC-RESISTANCE TESTS

These tests determine the ability of insulating materials to withstand severe arcing before the insulation surfaces become conducting.

8-78. OVERPOTENTIAL TESTING MACHINERY

Overpotential tests are applied to machinery to demonstrate the ability of the insulation to withstand a certain level of voltage. Industry standards establish levels of overpotential tests for all classes and types of windings. Generally intentionally destructive tests are made only for engineering information.

8-79. OVERPOTENTIAL TESTING PROCEDURE

The objective of a dielectric test on a winding is to determine if the insulation will withstand a certain voltage for a definite time. The test conditions must be controlled along the following lines:

Do's

1. Ground all windings not under test.
2. Apply test voltage in steps or by increasing with a variable voltage controller.
3. Test circuit must be connected to winding before voltage is applied.
4. Apply test voltage for a specified time.
5. Check physical size of winding, and calculate required transformer capacity.
6. Be sure the test transformer is of ample size for the capacitance of the winding under test.

Don'ts

1. Don't leave any circuits ungrounded.
2. Don't apply test voltage suddenly or in a single step.
3. Don't use test prongs to interrupt or apply voltage to winding under test.
4. Don't forget to watch the time test voltage is applied.
5. Don't use makeshift equipment, especially on large windings.

8-80. IMPULSE TESTS

Surge or impulse tests consist of applying steep-front voltage surges of very short duration which travel through the winding as a wave. Surge strength of solid insulation is higher than the peak of the proved 1-minute a-c voltage test. If the voltage wave applied has an exceedingly steep front, it may concentrate voltage stresses on the turn insulation in certain parts of the winding (usually the first few turns).

8-81. TURN-INSULATION TESTING

Most turn insulation on electric machinery is only positive separation or spacing. Mica-tape insulation may be considered as a dielectric barrier. Where individual turns of coils are not connected, they may be tested with conventional overpotential test equipment. Where the turns of a coil or winding are a continuous electrical circuit, specialized test equipment is required. Voltage may be introduced into a continuous winding by a growler or by the application of a surge or high-frequency test to the winding terminals. Surge or high-frequency methods permit the application of high turn-to-turn voltages and employ sensitive fault-detection means.

8-82. INSULATION-RESISTANCE TESTING MACHINERY

Insulation resistance of electric machine windings is affected by construction, moisture, temperature, cleanliness, and age and condition of windings. Field windings have inherently higher insulation-resistance values than armature windings on either a-c or d-c machines. D-c armature windings have lower insulation resistance than a-c machine armature windings of equivalent rating due to the existence of numerous creepage paths at the commutator. The insulation resistance of class A insulation is usually lower than class B insulation, and the insulation resistance of class B insulation is usually lower than class H insulation. The insulation resistance of duplicate machines will vary widely depending upon conditions during manufacture. Insulation resistance, though not a measure of dielectric strength, is a useful indication of winding condition. Periodic insulation-resistance readings indicate trends in insulation condition. When making insulation resistance tests, observe the following precautions:

Do's

1. Disconnect as much of the cable and connected equipment as practical.
2. Disconnect the windings or parts of the windings from each other when preliminary checks indicate unusually low insulation resistance.

3. Make measurements with the test voltage applied between the copper conductors and the metallic frame.

4. Correlate observations with time of voltage application.

5. Plot insulation-resistance values (after correction for temperature) on a chart to show trend with seasons.

Don'ts

1. Don't completely isolate the winding until preliminary tests are made.

2. Don't retest until winding has been discharged by grounding it.

3. Don't test one winding with other windings "floating" (ungrounded).

8-83. INTERPRETING INSULATION-RESISTANCE DATA

1. Relatively low value of insulation resistance may not indicate unfitness for service on new windings.

2. Insulation resistance increases on new windings owing to further cure of varnish treatment and evaporation of slight amounts of residual solvent and moisture.

3. Periodic tests are of value in detecting changes as a result of contamination or insulation weaknesses.

4. High insulation resistance is not always proof of good condition.

5. Dry and clean insulation will continue to increase in insulation resistance for a long period after test voltage is applied. Wet and dirty insulation reaches ultimate insulation-resistance value quickly after test voltage is applied.

Insulation resistance of duplicate machines will vary widely. There is less significance to the absolute insulation-resistance value among different machines than the trends of change for a particular machine.

A reasonable approximation of insulation-resistance value can be obtained from several formulas, but they are not precise, nor do they follow a natural law.

Leakage insulation resistance of end windings and creepage surfaces predominates on d-c machines in service.

8-84. DIELECTRIC ABSORPTION TEST

Insulation-resistance tests extended to very long times determine dielectric absorption. Data are accumulated at several times of voltage applications and plotted to show the time effect. Polarization index is the ratio of the 10-minute insulation resistance to the 1-minute insulation resistance. Polarization index of 3 to 4 is excellent and below 1½ questionable.

8-85. MAINTENANCE TESTING

1. Overpotential testing of insulation gives limited assurance of the absence of seriously conducting paths.

2. Overpotential testing of insulation may be damaging where the probable breakdown region is approached.

3. Maintenance overpotential tests are used to produce failures when repairs can be made conveniently.

4. Weeding out defective insulation without damaging good insulation is still an unsolved problem.

5. Insulation-resistance tests at 500 volts dc are usually considered nondestructive.

Maintenance overpotential tests on insulation are usually in the range of 60 to 75 percent of the original 1-minute test for new insulation.

8-86. EMERGENCY TESTS

Testing of insulation requires a source of voltage and fault-detection means. Either a-c or d-c voltage sources are reasonably satisfactory. D-c voltage should be about equal to 1.6 times the a-c rms voltage which

would normally be used. For fault detection, milliammeters or microammeters are suitable. Low-power lamps can also be used. It is important to establish acceptable levels of insulation where makeshift tests are used.

8-87. PREVENTIVE MAINTENANCE PROGRAM

The maintenance of electrical apparatus is principally concerned with its insulation. Other parts need periodic attention, but usually their failure does not require immediate shutdown of the apparatus. When insulation fails, a temporary shutdown is always necessary and frequently prolonged outages are necessary. It is therefore important to prevent insulation failures where possible. Many insulation failures can be prevented by selection of the proper insulation for the particular duty in the first place. Preventive maintenance work is preferable to replacement after trouble occurs. Repair with poorly selected insulating materials is an unsatisfactory type of maintenance and may result in repeated failure with possible injuries to personnel and serious consequential damage to associated equipment.

Electrical insulation does not require unusual care to maintain it in satisfactory and serviceable condition. Planned inspection and maintenance programs are very desirable. These should include:

1. Regular scheduled inspections.
2. Records of troubles and their correction.
3. Providing spare units, coils, and components.
4. Maintaining replacement units in usable condition.

Careful observation of new installations may disclose unusual conditions which might lead to early failure. For example, **excessive temperature for the insulation class will greatly reduce life.** Where humidity conditions are severe, more frequent inspection and revarnishing are beneficial. Records of all inspections and tests with reports of troubles found are an important aid to correction of troubles and prevention of similar difficulties elsewhere.

Preventive maintenance is better than emergency repair after failure occurs.

8-88. INSPECTION SCHEDULE

Inspection may provide advance notice of trouble. The attributes of the inspector are important. He should be intelligent, conscientious, and observant. These qualities are as important as his training and background. Periodic inspections for various conditions should be made weekly, monthly, or semiannually as recommended earlier in the text (Sec. 7-2).

8-89. INSULATION RESISTANCE

Rigid minimum values for permissible insulation resistance cannot be established as positive indication of incipient failure. However, experience has made it possible to set up limiting values of insulation resistance as a general guide in the maintenance of electrical equipment. See Secs. 7-10 to 7-14 for the method of establishment of these limiting values under various conditions.

8-90. SAFETY PRECAUTIONS

Before working on electrical equipment be sure that the equipment is disconnected from power and cannot be accidentally energized. In case of doubt check circuits with a voltage tester. Check wiring diagram to determine if there are any capacitors which should be discharged before

handling the apparatus. Windings of machines may also be charged like capacitors.

8-91. PURPOSE OF MAINTENANCE

The maintenance of electrical equipment is to ensure that the apparatus will function satisfactorily and that it is ready for service in all respects.

8-92. PERIODIC CLEANING

Regular cleaning is a big step to ensure trouble-free operation. There should be a definite period established for cleaning each piece of equipment at reasonable intervals. Cleaning offers an excellent opportunity for careful inspection. In establishing periods for cleaning and inspection remember that:

1. New equipment should be carefully watched in the early stages of operation.
2. Old equipment needs more frequent cleaning and inspection.
3. Time spent cleaning and correcting defects is time saved in repairs.

8-93. RECORDS AND REPAIRS

Records add greatly to the value of inspection, as they may reveal progressive deterioration. They may also reveal repetitive repair jobs which require investigation. Such facts form the basis for improvements in design, appearance, or methods of operation.

8-94. PAINTING ELECTRICAL EQUIPMENT

Renewal of paint on electrical equipment should be avoided where possible. Scraping or chipping tools must not be used. Paint dust is abrasive and semiconducting, and its presence may damage insulation. Windings should be protected from paint dust in the vicinity. After paint removal windings should be cleaned with a vacuum cleaner. Electrical apparatus should not be painted for the sole purpose of improving its appearance. Paint should never be applied to any insulating surfaces. They should only be coated with approved types of insulating varnish or compound.

8-95. EFFECT OF MOISTURE

Moisture is one of the greatest enemies of insulation. It may come from humid air or water from one of many possible other sources. It is absolutely imperative to keep electrical equipment dry to ensure long life and reliability.

8-96. KEEPING EQUIPMENT DRY

Space heaters are installed on many important electric machines to provide heat during idle periods so that the insulation can be kept dry. It is particularly important to use these heaters in humid or cold climates. Emergency heat can be supplied with electric lamps. A temperature 5 to 10 degrees F above ambient air will keep insulation in usable condition.

There are many ways in which insulation can be protected from water on shipboard such as:

1. Drip pans over the equipment.
2. Keeping seals at cable ends in good condition.
3. Coating absorbent surfaces of insulation with varnish or compound.
4. Keeping watertight joints crack-free.
5. Keeping water and oil out of the bottoms of machines by draining as necessary.
6. Preventing water in the bilges from flooding equipment or cables.
7. Taking inlet air for machines above the floor-plate level.

8. Using plastic sealer around cable terminals.

8-97. INSULATION CONTAMINATION

There is a kind of electrical failure which appears mysterious to the uninitiated, when the cause is relatively simple. Many ionizable substances are good insulators when dry but are highly conducting in the presence of moisture. These ionizable materials, if present on insulation surfaces or in insulation, often produce failure under humid conditions. Among these are:

1. Acid soldering fluxes.
2. Salt from sea water.
3. Alkaline-type protective hand creams.
4. Germicidal additions to lubricating oils.

These contaminants are hard to find until they cause trouble. Here again, prevention is better than cure.

8-98. CONCLUSION

Insulation design, application, operation, and maintenance present many complex problems. Often there may be several possible solutions, each having its peculiar advantages and disadvantages. Selecting the best over-all method, process, material, or test frequently requires compromise and the exercise of considerable engineering judgment. In approaching such problems, no matter of what magnitude, it is important to think in terms of objectives first. Then details of construction, materials, and methods should be considered later. Most controversies and differences in opinion arise from failure to review and agree on objectives or to define the basic problem. An objective view of a problem in broad perspective is an excellent start toward a real solution. This is especially applicable to insulation engineering.

Glossary

A stage (of resin). The condition of low molecular weight of a resin polymer during which the resin is readily soluble and fusible.

B stage (of resin). The condition of a resin polymer when it is more viscous, with higher molecular weight, being insoluble but plastic and fusible.

C stage (of resin). The condition of a resin polymer when it is in the solid state, with high molecular weight, being insoluble and infusible.

Capacitance. The ability of a capacitor to store an electric charge.

Capacitor. A system of conductors and dielectrics which is capable of storing an electric charge.

Catalyst. A substance which initiates and/or accelerates a chemical reaction but normally does not enter into the reaction.

Coat. To cover with a finishing, protecting, or enclosing layer of any compound (such as varnish).

Copolymer. A compound resulting from the chemical reaction of two chemically different monomers with each other.

Corona. The discharge of electricity which appears on the surface of a conductor when the potential gradient exceeds the critical voltage of the surrounding gas.

Creepage surface. An insulating surface which provides physical separation as a form of insulation between two electrical conductors of different potential.

Critical voltage (of gas). The voltage at which a gas ionizes and corona occurs, preliminary to dielectric breakdown of the gas.

Dielectric. An electrical insulating material.

Dielectric strength. The voltage which an insulating material can withstand before breakdown occurs, usually expressed as a voltage gradient (such as volts per mil).

Dipping. The process of impregnating or coating insulating materials, coils, or windings by the simple method of immersion in the treating liquid.

Drier. A material (usually a metallic oxide) which aids in the drying of oils and resins employed in varnishes.

Drying oil. An oil which on exposure to air absorbs oxygen to form products of higher molecular weight and dries to a hard film (may be either brittle or elastic).

Electrolyte. A substance which, when dissolved in a suitable liquid (often water), dissociates into ions, thus rendering liquid electrically conducting.

Eutectic point. The point of maximum fusibility of an alloy where the mixture will have the lowest melting point possible.

Fiber. A thread or threadlike structure such as comprises cellulose, wool, silk, or glass.

Fibre. A specific form of chemically gelled fibrous materials fabricated into sheets, rods, tubes, and the like.

Flex life. The time of heat aging that an insulating material can withstand before failure when bent around a specific radius (used to evaluate thermal endurance).

Flux, magnetic. The magnetic lines of force produced by a magnet or those magnetic lines surrounding electrical conductors carrying current.

Flux, soldering and brazing. A substance used to promote soldering, brazing, or welding action by freeing the surfaces to be joined of oxide, thus promoting their union.

Gradient. Rate of increase or decrease of a variable magnitude.

Heat endurance. The time of heat aging that a material can withstand before failing a specific physical test.

Impregnate. To fill the voids and interstices of a material with a compound. (This does not imply complete fill or complete coating of the surfaces by a hole-free film.)

Impulse. A surge of unidirectional polarity.

Inorganic. Designating or composed of matter other than animal or vegetable, such as earthy or mineral matter.

Interstice. A minute space between one thing and another, especially between things closely set or between the parts of a body.

Ion. An electrified portion of matter of subatomic, atomic, or molecular dimensions such as is formed when a molecule of gas loses an electron (when the gas is stressed electrically beyond the critical voltage) or when a neutral atom or group of atoms in a fluid loses or gains one or more electrons.

Liquidus. The temperature above which a material, such as a solder, becomes completely liquid.

Monomer. The simple, unpolymerized form of a compound which is the building block of a polymer.

Organic. Designating or composed of matter originating in plant or animal life or composed of chemicals of hydrocarbon origin, either natural or synthetic.

Overpotential. A voltage above the normal operating voltage of a device or circuit.

Polymer. A compound formed by polymerization which results in the chemical union of monomers or the continued reaction between lower molecular weight polymers.

Polymerize. To unite chemically two or more monomers or polymers of the same kind to form a molecule with higher molecular weight.

Random winding. A winding wherein the wires do not lie in an even pattern.

Slot armor. The insulating member within the slot of a magnetic core of a machine.

Slot cell. The same as slot armor.

Solidus. The temperature below which a material such as solder is completely solid.

Striking distance. The effective distance between two conductors separated by an insulating fluid. (Air clearance is typical.)

Surge. A transient variation in the current and/or potential at a point in the circuit.

Thermoplastic. A classification of resin that can be readily softened and resoftened by repeated heating.

Thermosetting. A classification of resin which cures by chemical reaction when heated and, when cured, cannot be resoftened by heating.

Throw (of coils). The span between the bottom leg of a coil and the top leg of the same coil expressed in the number of core slots spanned.

Treating. Any of the processes of applying varnishes or other insulating compounds to insulation, coils, or windings. This includes the processes of impregnation and of coating by any of the various methods.

Wrapper. An insulating barrier applied to a coil in sheet form by wrapping around the coil periphery.

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Appendix I. ELECTRICAL INSULATING MATERIALS— DESCRIPTION AND STOCK LIST

This appendix lists available Navy insulating materials and gives general identifying information. It has been prepared for the purpose of assisting shop personnel in the selection of the correct electrical insulating materials for the maintenance and repair of electrical equipment.

All materials as listed have been taken from the General Stores Section of the Catalog of Navy Material as follows: Class 15, Group 4, Magnet Wire; Class 17, Group 22, Electrical Insulating Materials; Class 52, Insulating Varnishes.

As this appendix is to be used only as a guide and for ready reference purposes, all ordering of materials should be made from the Catalog of Navy Material, which contains the latest ordering information, stock number and item changes, and general instructions.

Insulation, Electrical, Sheet

An electrical insulation item consisting of (1) condensed fibers, natural or synthetic, in sheet form such as paper, fibre, or glass (usually short fibers); (2) natural or synthetic rubber with or without reinforcement; or (3) a reinforced flat laminated (plastic) composite structure.

PAPER AND FIBRES

FISH PAPER (SLOT CELL)
Spec: JAN-I-695 Insulation Class O

Type F. An extremely tough, strong, dense fish paper made from chemically treated cotton rag stock. Available in roll form, 100 pounds per roll, in widths from 36 to 60 inches and in sheet form 36 × 36 inches minimum to 60 × 88 inches maximum.

Unit of Issue: Pound Approximate cost: $0.50 per pound

Stock No.	Thickness, in.	Sq ft per lb
Type F, Form R (Rolls):		
G17-I-4500	0.005	28.12
G17-I-4505	0.007	20.08
G17-I-4510	0.010	14.06
G17-I-4520	0.015	9.56
Type F, Form S (Sheets):		
G17-I-4530	0.020	7.00
G17-I-4540	0.025	5.60
G17-I-4550	0.030	4.70

Rag Paper

Spec: JAN–I–695 Insulation Class O

Type R. An extremely tough, dense, strong rag paper made from 100 percent selected cotton rag stock not chemically treated. Available in sheet form 36 × 36 inches minimum to 60 × 88 inches maximum.

Unit of issue: Pound Approximate cost: $0.70 per pound

Stock No.	Thickness, in.	Sq ft per lb
G17–I–4655–50	0.005	23.60
G17–I–4655–100	0.007	16.90
G17–I–4655–200	0.010	11.80
G17–I–4655–300	0.015	8.30
G17–I–4655–400	0.020	5.90
G17–I–4655–500	0.025	4.72
G17–I–4655–600	0.030	3.96

Pressboard

Spec: JAN–I–545 Insulation Class O

A dense, flexible, easily worked pressboard material made from rag stock. Has 300 volts per mil average dielectric strength. Available in sheet form, 30 × 36 inches minimum to 36 × 42 inches maximum.

Unit of issue: Pound Approximate cost: $0.30 per pound

Stock No.	Thickness, in.	Sq ft per lb
G17–I–4600	0.010	16.00
G17–I–4610	0.015	10.66
G17–I–4620	0.020	8.00
G17–I–4630	0.025	6.40
G17–I–4640	0.030	5.33
G17–I–4650	0.060	2.66
G17–I–4650–125	0.125	1.33

Hard Fibre

Spec: JAN–F–1148 Insulation Class O

Grade BH (Bone Hard). A high-density material of chemically gelled paper stock having excellent machining qualities, arc resistance, and toughness and a specific gravity of not less than 1.30. Available in sheet form in sizes from 30 × 55 inches minimum to 60 × 84 inches maximum.

Unit of issue: Pound Approximate cost: $0.50 per pound

Stock No.	Thickness, in.	Lb per sq ft
G17–I–2130	1/32	0.212
G17–I–2140	1/16	0.423
G17–I–2150	3/32	0.635
G17–I–2160	1/8	0.846
G17–I–2170	3/16	1.269
G17–I–2180	1/4	1.692
G17–I–2190	3/8	2.538
G17–I–2200	1/2	3.384

Vulcanized Fibre

Spec: JAN–F–1148 Insulation Class O

Grade CH (Commercial or Vulcanized). A dense material of chemically gelled paper stock similar to bone hard except specific gravity is in the order of 1.10. Available in sheet form in sizes from 30 × 55 inches minimum to 60 × 88 inches maximum.

Unit of issue: Pound Approximate cost: $0.70 per pound

Stock No.	Thickness, in.	Lb per sq ft
G17–I–2320	5/8	3.148
G17–I–2330	3/4	4.102
G17–I–2340	7/8	4.785
G17–I–2350	1	5.47
G17–I–2360	1 1/8	6.152
G17–I–2361	1 1/4	6.8360
G17–I–2362	1 1/2	8.2029

LAMINATES

Paper Base, Form S

Spec: MIL–P–3115A Insulation Class A

Type PBE. A natural-color, paper-base, phenolic laminate for use in radio-frequency applications. Has good electrical properties under high-humidity conditions. Arc resistance and fire resistance are poor. Available in sheets in sizes between 36 and 50 inches in width and between 36 and 96 inches in length.

Type PBG. A general-purpose, natural-color, paper-base, phenolic laminate combining fairly good electrical and mechanical properties. Arc resistance and fire resistance are poor. Available in sheets in sizes between 36 and 50 inches in width and between 36 and 96 inches in length.

Unit of issue: Pound — Approximate cost: $1.00 per pound

Stock No.	Thickness, in.	Lb per sq ft
Type PBE (Paper-base Electrical):		
G17–I–5636–50	1/32	0.22
G17–I–5636–70	1/16	0.44
G17–I–5636–80	3/32	0.66
G17–I–5636–90	1/8	0.88
G17–I–5636–110	3/16	1.33
G17–I–5636–130	1/4	1.77
G17–I–5636–140	5/16	2.12
G17–I–5636–150	3/8	2.66
G17–I–5636–170	1/2	3.54
G17–I–5636–180	5/8	4.42
G17–I–5636–190	3/4	5.32
G17–I–5636–200	7/8	6.20
G17–I–5636–210	1	7.08
G17–I–5636–230	1 1/4	8.85
G17–I–5636–250	1 1/2	10.63
Type PBG (Paper-base General):		
G17–I–5700–50	1/32	0.22
G17–I–5700–70	1/16	0.44
G17–I–5700–80	3/32	0.66
G17–I–5700–90	1/8	0.88
G17–I–5700–110	3/16	1.33
G17–I–5700–130	1/4	1.77
G17–I–5700–140	5/16	2.12
G17–I–5700–150	3/8	2.66
G17–I–5700–170	1/2	3.54
G17–I–5700–180	5/8	4.42
G17–I–5700–190	3/4	5.32
G17–I–5700–200	7/8	6.20
G17–I–5700–210	1	7.08
G17–I–5700–230	1 1/4	8.85
G17–I–5700–250	1 1/2	10.63

Fabric Base, Form S

Spec: MIL–P–3114A — Insulation Class A

Type FBG. A general-purpose, natural-color, cotton-fabric-base, phenolic laminate combining fairly good electrical and mechanical properties. Arc resistance and fire resistance are poor. Available in sheets in sizes between 36 and 50 inches in width and between 36 and 96 inches in length.

Unit of issue: Pound — Approximate cost: $1.20 per pound

Stock No.	Thickness, in.	Lb per sq ft
G17–I–5531–125	1/32	0.22
G17–I–5531–175	1/16	0.45
G17–I–5531–200	3/32	0.67
G17–I–5531–225	1/8	0.90
G17–I–5531–275	3/16	1.35
G17–I–5531–325	1/4	1.80
G17–I–5531–350	5/16	2.25
G17–I–5531–375	3/8	2.70
G17–I–5531–425	1/2	3.60
G17–I–5531–450	5/8	4.50
G17–I–5531–475	3/4	5.40
G17–I–5531–500	7/8	6.30
G17–I–5531–525	1	7.20
G17–I–5531–550	1 1/8	8.10
G17–I–5531–575	1 1/4	9.00
G17–I–5531–600	1 3/8	9.90
G17–I–5531–625	1 1/2	10.80
G17–I–5531–650	1 5/8	11.70
G17–I–5531–675	1 3/4	12.60
G17–I–5531–700	1 7/8	13.50
G17–I–5531–725	2	14.40

Glass Base, Form S

Spec: MIL–P–15037 — Insulation Glass B

Type GMG. A general-purpose, glass-fabric-base, melamine resin laminate combining good electrical properties with high mechanical strength. Has excellent fire- and arc-resistance properties. Available in sheet in sizes between 36 and 50 inches wide and between 36 and 96 inches in length.

Unit of issue: Pound — Approximate cost: $2.40 per pound

Spec: MIL–P–997 — Insulation Class H

Type GSG. A general-purpose, glass-fabric-base, silicone resin laminate combining excellent electrical properties with high-temperature resistance. Mechanical strength is good, and fire- and arc-resistant properties are high. Available in sheets in sizes between 36 and 50 inches wide and between 36 and 96 inches in length.

Unit of issue: Pound — Approximate cost: $7.50 per pound

Stock No.	Thickness, in.	Lb per sq ft
Type GMG (Glass Melamine General):		
G17-I-5765-5	1/32	0.31
G17-I-5765-10	1/16	0.62
G17-I-5765-15	3/32	0.93
G17-I-5765-20	1/8	1.24
G17-I-5765-25	3/16	1.86
G17-I-5765-30	1/4	2.48
G17-I-5765-35	5/16	3.10
G17-I-5765-40	3/8	3.72
G17-I-5765-45	1/2	4.96
G17-I-5765-50	5/8	6.20
G17-I-5765-55	3/4	7.44
G17-I-5765-60	7/8	8.68
G17-I-5765-65	1	9.92
G17-I-5765-70	1 1/8	11.16
G17-I-5765-75	1 1/4	12.40
G17-I-5765-80	1 3/8	13.64
G17-I-5765-85	1 1/2	14.88
G17-I-5765-90	1 5/8	16.12
G17-I-5765-95	1 3/4	17.36
G17-I-5765-100	1 7/8	18.60
G17-I-5765-105	2	19.84

Stock No.	Thickness, in.	Lb per sq ft
Type GSG (Glass Silicone General):		
G17-I-5764-31	1/32	0.20
G17-I-5764-62	1/16	0.40
G17-I-5764-93	3/32	0.60
G17-I-5764-125	1/8	0.80
G17-I-5764-187	3/16	1.20
G17-I-5764-250	1/4	1.60
G17-I-5764-312	5/16	2.00
G17-I-5764-375	3/8	2.40
G17-I-5764-500	1/2	3.20
G17-I-5764-625	5/8	4.00
G17-I-5764-750	3/4	4.80
G17-I-5764-875	7/8	5.60
G17-I-5764-1000	1	6.40
G17-I-5764-1125	1 1/8	7.20
G17-I-5764-1250	1 1/4	8.00
G17-I-5764-1375	1 3/8	8.80
G17-I-5764-1500	1 1/2	9.60
G17-I-5764-1625	1 5/8	10.40
G17-I-5764-1750	1 3/4	11.20
G17-I-5764-1875	1 7/8	12.00
G17-I-5764-2000	2	12.80

PASTED MICA

Spec: HH-I-538 — Insulation Class B

Class PM, Form S

Type PMF (pasted mica, flexible) is suitable for forming or being applied onto ordinary shapes without any application of heat. Average short-time dielectric strength, 525 volts per mil.

Type PMM (pasted mica, moldable) is capable of being molded into special shapes and forms when heated to a temperature of 135 C. The molded form is retained upon cooling to room temperature. Average short-time dielectric strength, 600 volts per mil.

Type PMR (pasted mica, rigid) is capable of being safely bent to an 18-inch radius of curvature with no detrimental effects. Average short-time dielectric strength, 600 volts per mil. Furnished in sheets 18 inches wide and 36 inches long.

Unit of issue: Pound — Approximate cost: $3.00 per pound

Stock No.	Thickness, in.	Approx. sq ft per lb
Type PMF:		
G17-I-3340	0.005	16.48
G17-I-3350	0.010	9.00
G17-I-3360	0.015	6.12
G17-I-3370	0.020	4.74
G17-I-3380	0.025	3.90
G17-I-3390	0.030	3.10
G17-I-3400	0.035	2.68
G17-I-3410	0.0375	2.57
G17-I-3420	0.040	2.41
G17-I-3430	0.045	2.05
G17-I-3440	0.050	1.88
G17-I-3450	0.125	0.75

Stock No.	Thickness, in.	Approx. sq ft per lb
Type PMM:		
G17–I–2650	0.005	16.95
G17–I–2660	0.010	8.47
G17–I–2670	0.015	5.65
G17–I–2680	0.020	4.10
G17–I–2690	0.025	3.22
G17–I–2700	0.030	2.60
G17–I–2710	0.035	2.45
G17–I–2720	0.0375	2.25
G17–I–2730	0.040	1.95
G17–I–2740	0.045	1.72
G17–I–2750	0.050	1.51
G17–I–2760	0.125	0.59

Stock No.	Thickness, in.	Approx. sq ft per lb
Type PMR:		
G17–I–2920	0.020	6.43
G17–I–2940	0.025	5.14
G17–I–2950	0.030	4.28
G17–I–2960	0.035	3.67
G17–I–2970	0.040	3.21
G17–I–2973	0.045	2.85
G17–I–2976	0.050	2.57

MICA–GLASS COMBINATIONS

Spec: 17–I–62

Class B, Form S, with organic varnish

Class H, Form S, with silicone varnish

Type GMG (Glass-Mica-Glass). Consists of pasted mica sandwiched between single layers of glass cloth.

Type MG (Mica-Glass). Consists of pasted mica laminated with one layer of glass cloth.

Type PMG (Paper-Mica-Glass). Consists of pasted mica laminated with one layer of thin paper on one side (for mechanical support) and one layer of glass cloth on the other side.

The above three types of material are used for motor, generator, and transformer coils, slot liners, ground insulation, phase-to-phase insulation, primary and secondary separation, coil exteriors, cable splices, coil and cell wrappers, and similar uses. It has high dielectric strength.

Unit of issue: Square yard — Approximate cost: $10.00 per square yard

Stock No.	Thickness, in.
Class B, Type GMG:	
G17–I–4235–320	0.012
Class B, Type MG:	
G17–I–4232–175	0.010
Class B, Type PMG:	
G17–I–4235–650	0.007
G17–I–4235–675	0.015
Class H, Type GMG:	
G17–I–4235–400	0.010
G17–I–4235–420	0.012
Class H, Type MG:	
G17–I–4232–150	0.007

Insulation, Electrical, Cloth

An electrical insulation item consisting of woven fabric of natural or synthetic fibers such as cotton, silk, rayon, glass, asbestos, or nylon, usually in widths of over 8 inches; may be plain, impregnated, or varnished.

CLOTH

Cotton Fabric (Untreated)

Spec: MIL–I–3042 — Insulation Class O

Type CFU. A cotton-fiber cloth, relatively clean and free of deleterious substances. Has a balance weave of not less than 68 or more than 72 threads per inch and may be readily impregnated with insulating varnish. Available in 25- or 50-yard rolls of 35-inch width trimmed.

Unit of issue: Yard — Approximate cost: $0.80 per yard

Stock No.	Thickness, in.	Oz per sq yd
Type CFU (Cotton Fiber Untreated):		
G17–I (numbers not available)	0.005	2.40
G17–I (numbers not available)	0.007	2.80
G17–I (numbers not available)	0.010	2.80
G17–I (numbers not available)	0.012	2.80

VARNISHED CAMBRIC

Spec: 17–C–8 Insulation Class A

Type A. A uniform, square-woven, clean, cotton cloth coated with a high-grade slow-drying baking varnish. Has a smooth, high-gloss surface free from wrinkles and creases. Available in trimmed widths of 35 inches in rolls of 50 yards.

Unit of issue: Square yard Approximate cost: $1.00 per yard

Stock No.	Thickness, in.	Dielectric strength, volts
Type A:		
G17–I–1620	0.007	5,600
G17–I–1640	0.010	8,000

ASBESTOS FABRIC (UNTREATED)

Spec: MIL–I–3053 Insulation Class C

Type 4PU (Plain, Untreated). An asbestos-fiber cloth made from high-grade, long-fiber asbestos uniformly woven and free from knots, lumps, and unsightly defects and containing not less than 85 percent by weight of pure asbestos. Available in rolls 36 inches wide.

Type 4RU (Reinforced, Untreated). Same as type 4PU except stronger.

Unit of issue: Square yard Approximate cost: $2.00 per square yard

Stock No.	Thickness, in.	Oz per sq yd
Type 4PU (Plain, Untreated):		
G17–I–1500–20	0.025	15
G17–I–1500–80	0.035	18
G17–I–1500–140	0.045	20

Stock No.	Thickness, in.	Oz per sq yd
Type 4RU (Reinforced, Untreated):		
G17–I–1500–30	0.025	15
G17–I–1500–90	0.035	18
G17–I–1500–150	0.045	20

GLASS FABRIC (UNTREATED)

Spec: MIL–I–1140 A Insulation Class C

Type GFU. A high-grade electrical cloth made from either continuous filament or staple fiber glass furnished in rolls 50 to 300 yards long in 38-inch widths.

Unit of issue: Square yard Approximate cost: $1.50 per square yard

Stock No.	Cloth No.	Thickness, in.	Oz per sq yd
Class CF, Continuous Filament:			
G17–I–2644–300	108	0.002	1.43
G17–I–2644–305	113	0.003	2.46
G17–I–2644–310	128	0.007	6.00
G17–I–2644–315	141	0.010	8.70
G17–I–2644–320	164	0.015	12.60
Class SF, Staple Fiber:			
G17–I–2644–400	261	0.015	10.32
G17–I–2644–405	294	0.023	14.70

VARNISHED GLASS CLOTH

Spec: 17–I–45 Insulation Class B

Group GFV, Grade O, Form C. A high-grade, varnished glass cloth using continuous-filament glass cloth and an organic insulating varnish. A general-purpose insulating material available in 25-linear-yard rolls, 36 inches wide trimmed.

Unit of issue: Square yard Approximate cost: $2.00 per square yard

Stock No.	Thickness, in.	Dielectric strength, volts
Grade O, Form C:		
G17–I–2641–905	0.005	6,250
G17–I–2641–915	0.007	8,750
G17–I–2641–925	0.010	11,000
G17–I–2641–935	0.012	12,000

SILICONE GLASS CLOTH
Spec: 17–I–45 Insulation Class H

Group GFV, Grade S, Form C. A high-grade, silicone-varnished glass cloth using continuous-filament glass cloth and a silicone varnish. A general-purpose, high-temperature insulating material available in 25-linear-yard rolls, 36 inches wide trimmed.

Unit of issue: Square yard Approximate cost: $4.00 per square yard

Stock No.	Thickness, in.	Dielectric strength, volts
Grade S, Form C:		
G17–I–2642–40	0.004	4,400
G17–I–2642–70	0.007	7,000
G17–I–2642–100	0.010	8,000
G17–I–2642–120	0.012	8,500

Insulation, Electrical, Tape

An electrical insulation item consisting of tape of any kind but usually consisting of woven fabric (less than 8 inches wide), slit film, or sheet material. Tape may be plain, impregnated, or varnished.

TAPE

COTTON TAPE, LINEN FINISH
Spec: JAN–T–638 Insulation Class O

Type I (Plain). A high-grade, uniformly woven cotton tape with a linen finish free from unsightly defects, lumps, knots, etc. Available in 72-yard rolls.

Unit of issue: Roll Approximate cost: $0.40 per roll

Stock No.	Thickness, in.	Width, in.
G17–T–1300	0.005	½
G17–T–1310	0.005	¾
G17–T–1305	0.007	½
G17–T–1315	0.007	¾
G17–T–1320	0.007	1
G17–T–1330	0.007	1½

VARNISHED CAMBRIC TAPE
Spec: 17–C–8 Insulation Class A

Type B (Bias Cut). A closely and uniformly woven cotton fabric treated with a high-grade, slow-baking organic varnish for general insulating purposes. Furnished in 36- and 72-yard rolls.

Unit of issue: Roll Approximate cost: $0.80 per roll

Stock No.	Thickness, in.	Width, in.
36-Yard rolls:		
G17–T–1118	0.007	¾
G17–T–1120	0.007	1
G17–T–1124	0.007	1¼
G17–T–1122	0.010	1
G17–T–1126	0.010	1¼
G17–T–1128	0.010	1½
G17–T–1130	0.012	1½
72-Yard rolls:		
G17–T–1170	0.007	¾
G17–T–1175	0.007	1
G17–T–1185	0.007	1¼
G17–T–1180	0.010	1
G17–T–1190	0.010	1¼
G17–T–1195	0.010	1½
G17–T–1200	0.012	1½

Friction Tape

Spec: HH-T-101 Insulation Class A

A general-purpose tape made from cotton sheeting, evenly and firmly woven from good cotton, free from defects, lumps, or twist. The fabric is thoroughly impregnated and evenly coated on both sides with a friction rubber compound. Available in rolls of 85 feet. Nominal thickness 0.015 inch. Dielectric strength 1,000 volts.

Unit of issue: Roll Approximate cost: $0.40 per roll

Stock No.	Width, in.
G17-T-805	¾
G17-T-810	1
G17-T-815	1½

Rubber Tape

Spec: HH-T-111 Insulation Class A

A general-purpose rubber adhesive tape of uniform width; evenly, smoothly, and well calendered; free from surface holes. Nominal thickness 0.027 inch. Dielectric strength 350 volts per mil.

Unit of issue: Roll Approximate cost: $0.40 per roll

Stock No.	Width, in.	Ft per roll
G17-T-1445	¾	30
G17-T-1460	2	15

Glass Tape (Untreated)

Spec: MIL-I-1140A Insulation Class C

Group GFU. A high-grade uniformly woven glass-fiber tape having high insulation resistance, high dielectric strength, and low moisture pickup. Tape furnished in 36-yard rolls except 0.003-inch tape, which is furnished in 72-yard rolls.

Unit of issue: Roll Approximate cost: $0.80 per roll

Stock No.	Thickness, in.	Width, in.	Yd per lb
Class CFC, ECC-11B, Continuous Filament, Close Weave			
G17-I-2645-2	0.003	⅜	558
G17-I-2645-4	0.003	½	403
G17-I-2645-6	0.003	¾	271
G17-I-2645-8	0.003	1	198
G17-I-2645-12	0.003	1½	117
G17-I-2645-14	0.005	⅜	268
G17-I-2645-16	0.005	½	208
G17-I-2645-18	0.005	¾	143
G17-I-2645-20	0.005	1	109
G17-I-2645-24	0.005	1½	74
G17-I-2645-26	0.007	⅜	222
G17-I-2645-28	0.007	½	172
G17-I-2645-30	0.007	¾	118
G17-I-2645-32	0.007	1	90
G17-I-2645-36	0.007	1½	61
Class CFM, ECC-11A, Continuous Filament, Medium Weave			
G17-I-2645-64	0.005	½	248
G17-I-2645-66	0.005	¾	178
G17-I-2645-68	0.005	1	135
G17-I-2645-72	0.005	1½	91
G17-I-2645-76	0.007	½	172
G17-I-2645-78	0.007	¾	123
G17-I-2645-80	0.007	1	93
G17-I-2645-84	0.007	1½	64
G17-I-2645-88	0.010	½	128
G17-I-2645-90	0.010	¾	86
G17-I-2645-92	0.010	1	65
G17-I-2645-96	0.010	1½	43
G17-I-2645-100	0.015	½	91
G17-I-2645-102	0.015	¾	63
G17-I-2645-104	0.015	1	48
G17-I-2645-108	0.015	1½	32

Stock No.	Thickness, in.	Width, in.	Yd per lb
CLASS SFM, ESS–13A, Staple Fiber, Medium Weave			
G17–I–2645–120	0.010	½	127
G17–I–2645–122	0.010	¾	83
G17–I–2645–124	0.010	1	65
G17–I–2645–128	0.010	1½	42
G17–I–2645–130	0.015	½	90
G17–I–2645–132	0.015	¾	60
G17–I–2645–134	0.015	1	45
G17–I–2645–138	0.015	1½	29
G17–I–2645–140	0.020	½	68
G17–I–2645–142	0.020	¾	49
G17–I–2645–144	0.020	1	36
G17–I–2645–148	0.020	1½	25
G17–I–2645–150	0.025	½	63
G17–I–2645–152	0.025	¾	44
G17–I–2645–154	0.025	1	32
G17–I–2645–158	0.025	1½	18

GLASS TAPE (VARNISHED)

Spec: 17–I–45 Insulation Class B

Group GFV, Grade O, Form T. A high-grade, varnished glass tape using continuous-filament glass and treated with organic varnish. A general-purpose tape available in 36-linear-yard rolls.

Unit of issue: Roll Approximate cost: $1.00 per roll

Stock No.	Thickness, in.	Width, in.
Grade O, Form T, Yellow:		
G17–I–2641–2500	0.005	½
G17–I–2641–2510	0.005	¾
G17–I–2641–2520	0.005	1
G17–I–2641–2530	0.005	1½
G17–I–2641–2600	0.007	½
G17–I–2641–2610	0.007	¾
G17–I–2641–2620	0.007	1
G17–I–2641–2630	0.007	1½
G17–I–2641–2700	0.010	½
G17–I–2641–2710	0.010	¾
G17–I–2641–2720	0.010	1
G17–I–2641–2730	0.010	1½
G17–I–2641–2800	0.012	½
G17–I–2641–2810	0.012	¾
G17–I–2641–2820	0.012	1
G17–I–2641–2830	0.012	1½

SILICONE GLASS TAPE

Spec: 17–I–45 Insulation Class H

Group GFV, Grade S, Form T. A high-grade glass tape treated with silicone varnish for high-temperature and extreme-moisture applications. Available in 36-linear-yard rolls.

Unit of issue: Roll Approximate cost: $2.00 per roll

Stock No.	Thickness, in.	Width, in.
Grade S, Form T:		
G17–I–2642–5450	0.004	½
G17–I–2642–5475	0.004	¾
G17–I–2642–5500	0.004	1
G17–I–2642–5550	0.004	1½
G17–I–2642–5750	0.007	½
G17–I–2642–5775	0.007	¾
G17–I–2642–5800	0.007	1
G17–I–2642–5850	0.007	1½
G17–I–2642–6050	0.010	½
G17–I–2642–6075	0.010	¾
G17–I–2642–6100	0.010	1
G17–I–2642–6150	0.010	1½
G17–I–2642–6350	0.012	½
G17–I–2642–6375	0.012	¾
G17–I–2742–6400	0.012	1
G17–I–2642–6450	0.012	1½

MICA-GLASS COMBINATIONS

Spec: 17–I–62

Class B, Form T, with organic varnish
Class H, Form T, with silicone varnish

Type GMG (Glass-Mica-Glass). Consists of pasted mica sandwiched between single layers of glass cloth.

Type MG (Mica-Glass). Consists of pasted mica laminated with one layer of glass cloth.

Type PMG (Paper-Mica-Glass). Consists of pasted mica laminated with one layer of thin paper on one side (for mechanical support) and one layer of glass cloth on the other side.

This material is used for generator, motor, and transformer coils; slot liners; ground insulation; phase-to-phase insulation; primary-secondary separation; coil exteriors; cable splices; coil and cell wrappers; and similar uses. It has high dielectric strength.

Unit of issue: Roll Approximate cost: $8.00 per square yard

Stock No.	Thickness, in.	Width, in.
Class B, Type PMG:		
G17–I–4235–800	0.007	½
G17–I–4235–820	0.007	¾
G17–I–4235–840	0.007	1
Class H, Type GMG:		
G17–I–4235–500	0.010	½
G17–I–4235–520	0.010	¾
G17–I–4235–540	0.010	1
Class H, Type MG:		
G17–I–4235–100	0.0035	½
G17–I–4235–120	0.0035	¾
G17–I–4235–140	0.0035	1
G17–I–4235–200	0.007	½
G17–I–4235–220	0.007	¾
G17–I–4235–240	0.007	1

ASBESTOS TAPE (UNTREATED)
Spec: MIL–I–3053 Insulation Class C

Class 4, *Type* 4*PU*. A medium-quality asbestos tape where electrical properties are of secondary importance. Furnished in 36-yard rolls. Minimum dielectric strength 25 volts per mil.

Unit of issue: Roll Approximate cost: $1.00 per roll

Stock No.	Thickness, in.	Width, in.
G17–I–1545–10	0.015	½
G17–I–1545–40	0.015	¾
G17–I–1545–70	0.015	1
G17–I–1545–100	0.015	1¼
G17–I–1545–130	0.015	1½
G17–I–1545–160	0.020	1
G17–I–1545–190	0.025	½
G17–I–1545–220	0.025	¾
G17–I–1545–250	0.025	1
G17–I–1545–280	0.025	1¼
G17–I–1545–310	0.025	1½
G17–I–1545–340	0.030	1¼

SYNTHETIC FIBER, WOVEN (UNTREATED)
Spec: 17–I–34 Insulation Class O

Group SFU, *Form T*. A woven synthetic fiber tape for general-purpose insulation use. Furnished in 36-yard rolls.

Unit of issue: Roll Approximate cost: $1.00 per roll

Stock No.	Thickness, in.	Width, in.
Type HMHR (High Mechanical and Heat Resistance)		
G17–T–1736–100	0.003	⅜
G17–T–1736–105	0.003	½
G17–T–1736–110	0.003	⅝
G17–T–1736–130	0.005	⅜
G17–T–1736–135	0.005	½
G17–T–1736–140	0.005	⅝
Type MMHR (Medium Mechanical and Heat Resistance)		
G17–T–1737–100	0.003	⅜
G17–T–1737–105	0.003	½
G17–T–1737–110	0.003	⅝
G17–T–1737–130	0.005	⅜
G17–T–1737–135	0.005	½
G17–T–1737–140	0.005	⅝

SYNTHETIC FIBER, WOVEN (TREATED)
Spec: 17–I–34 Insulation Class A

Group SFT, *Form T*. A woven, synthetic fiber tape treated with an organic varnish and used for general insulation applications. Furnished in nonbonding (class 2) only and in 36-yard rolls.

Unit of issue: Roll Approximate cost: $1.00 per roll

Stock No.	Thickness, in.	Width, in.
G17–I–5776–300	0.003	⅜
G17–I–5776–305	0.003	½
G17–I–5776–310	0.003	⅝
G17–I–5776–350	0.004	⅜
G17–I–5776–355	0.004	½
G17–I–5776–360	0.004	⅝
G17–I–5776–400	0.005	⅜
G17–I–5776–405	0.005	½
G17–I–5776–410	0.005	⅝

SYNTHETIC RESIN
Spec: JAN–I–631 Insulation Class A

Type F, Grade A, Form T. A high-elongation elastic material with good electrical properties suitable as an alternate for rubber tape. Furnished in black only in rolls 4½ inches in diameter for hand taping.

Unit of issue: Roll Approximate cost: $1.50 per roll

Stock No.	Thickness, in.	Width, in.
Type F, Grade A:		
G17–I–5797–50	0.010	½
G17–I–5797–55	0.010	¾
G17–I–5797–60	0.010	1
G17–I–5797–61	0.010	1¼
G17–I–5797–62	0.010	1½
G17–I–5797–65	0.020	½
G17–I–5797–70	0.020	¾
G17–I–5797–75	0.020	1

SYNTHETIC RESIN (ADHESIVE)
Spec: 17–T–28 Insulation Class A

Type VF. A pressure-sensitive adhesive, vinyl chloride-acetate backing, black tape 0.010 inch thick. Furnished in 36-yard rolls.

Unit of issue: Roll Approximate cost: $0.40 per roll

Stock No.	Thickness, in.	Width, in.
G17–T–1745–35	0.010	½
G17–T–1745–60	0.010	¾
G17–T–1745–200	0.010	1
G17–T–1745–250	0.010	1¼
G17–T–1745–300	0.010	1½

Insulation, Electrical, Rod

An electrical insulation item consisting of a solid bar, usually circular and long in proportion to its breadth and thickness.

FIBRE

FIBRE RODS
Spec: JAN–F–1148 Insulation Class O

Grade BH. Extra-hard dense stock commonly referred to as "bone hard."

Unit of issue: Foot Approximate cost: $0.15 per foot

Grade CH. A hard fibre stock commonly referred to as "commercial" or "vulcanized."

Unit of issue: Foot Approximate cost: $0.50 per foot

Stock No.	Diameter, in.
Grade BH:	
G17–I–1799–950	3/32
G17–I–1799–975	⅛
G17–I–1800	3/16
G17–I–1810	¼
G17–I–1820	5/16
G17–I–1830	⅜
G17–I–1840	½
Grade CH:	
G17–I–1950	⅝
G17–I–1960	¾
G17–I–1970	⅞
G17–I–1980	1
G17–I–1990	1⅛
G17–I–2000	1¼
G17–I–2010	1½
G17–I–2020	1¾
G17–I–2030	2

PLASTICS

Paper Base, Form R
Spec: MIL–P–79 Insulation Class A

Type PBG. A general-purpose material having fair electrical and mechanical properties. Has poor fire and arc resistance. Supplied in natural color in length of approximately 36 inches.

Unit of issue: Foot Approximate cost: $0.70 per foot

Stock No.	Diameter, in.
Type PBG:	
G17–I–5683–610	¼
G17–I–5683–630	5/16
G17–I–5683–640	⅜
G17–I–5683–655	½
G17–I–5683–670	⅝
G17–I–5683–685	¾
G17–I–5683–700	⅞
G17–I–5683–715	1

Fabric Base, Form R
Spec: MIL–P–79 Insulation Class A

Type FBE. A linen-fabric-base, laminated rod having fairly good electrical properties suitable for fine machining operations. Supplied in natural color in lengths of approximately 36 inches.

Unit of issue: Foot Approximate cost: $0.90 per foot

Stock No.	Diameter, in.
G17–I–5478–500	⅝
G17–I–5478–510	¾
G17–I–5478–520	⅞
G17–I–5478–530	1
G17–I–5478–570	1½
G17–I–5478–635	2

Glass Base, Form R
Spec: MIL–P–79 Insulation Class B

Type GMG. A fire- and arc-resistant laminated rod with good electrical properties and excellent mechanical strength. Supplied in natural color only.

Unit of issue: Foot Approximate cost: $2.00 per foot

Stock No.	Diameter, in.
G17–I–5762–975	3/16
G17–I–5763–45	¼
G17–I–5763–50	5/16
G17–I–5763–65	⅜
G17–I–5763–80	½
G17–I–5763–95	⅝
G17–I–5763–110	¾
G17–I–5763–125	⅞
G17–I–5763–140	1
G17–I–5763–145	1⅛
G17–I–5763–150	1¼
G17–I–5763–155	1½
G17–I–5763–170	2
G17–I–5763–190	2¼
G17–I–5763–250	3

Insulation, Electrical, Cordage

An electrical insulation item consisting of (1) a twisted yarn of organic or inorganic fibers or (2) an extruded synthetic plastic flexible rod, usually less than ⅛ inch diameter.

GLASS FIBER

Twisted Cord
Spec: MIL–I–1140A Insulation Class C

Group GFU, Class CF. An untreated, continuous-filament, twisted glass-fiber cord with high tensile strength suitable for wire-tying purposes.

Unit of issue: Pound Approximate cost: $0.85 per pound

Stock No.	Cord No.	Diameter, in.	Yd per lb
G17–I–2644–500	EC5–1–U	1/64	3,533
G17–I–2644–505	EC5–2–U	1/32	750
G17–I–2644–510	EC5–3–U	3/64	410
G17–I–2644–515	EC5–4–U	1/16	192
G17–I–2644–520	EC5–5–U	5/64	156
G17–I–2644–525	EC5–6–U	3/32	130
G17–I–2644–535	EC5–8–U	⅛	92

Insulation, Electrical, Sleeving

A flexible electrical insulation item consisting of a hollow cylindrical plastic extrusion or a round woven fabric.

SLEEVING

Cotton, Braided (Untreated)

Spec: MIL–I–3042 Insulation Class O

Type CFU. A braided cotton sleeving which readily absorbs insulating varnish. Flexible and suitable for insulating bare wire, leads, and rods.

Unit of issue: Pound Approximate cost: $1.80 per pound

Stock No.				ID, in.	Wall thickness, in.	Approx. yd per lb	Covers AWG (bare) wire
Black	Blue	Gray	Red				
G17–S–8300	G17–S–8465	G17–S–8630	G17–S–8800	0.031	0.014	720	18–20
G17–S–8310	G17–S–8475	G17–S–8640	G17–S–8810	0.064	0.016	280	13–18
G17–S–8315	G17–S–8480	G17–S–8645	G17–S–8815	0.081	0.017	250	11–12
G17–S–8325	G17–S–8490	G17–S–8655	G17–S–8825	0.128	0.018	225	9–10
G17–S–8330	G17–S–8495	G17–S–8660	G17–S–8830	0.162	0.017	125	6–7
G17–S–8335	G17–S–8500	G17–S–8665	G17–S–8835	0.204	0.018	100	4–5
G17–S–8345	G17–S–8510	G17–S–8675	G17–S–8845	0.258	0.018	80	2–3
G17–S–8350	G17–S–8515	G17–S–8680	G17–S–8850	0.289	0.018	75	1–2
G17–S–8355	G17–S–8520	G17–S–8685	G17–S–8855	0.325	0.018	65	0–1
G17–S–8360	G17–S–8525	G17–S–8690	G17–S–8860	0.375	0.018	60	00–0
G17–S–8365	G17–S–8530	G17–S–8695	G17–S–8865	0.438	0.018	50	000–00

Asbestos, Braided (Untreated)

Spec: MIL–I–3053 Insulation Class C

Class 4, *Type* 4*PU* (*Plain, Untreated*). A braided asbestos fiber sleeving which readily absorbs insulating varnish. Flexible and suitable for insulating bare wire, leads, and rods.

Unit of issue: Pound Approximate cost: $3.00 per pound

Stock No.	ID, in.	Approx. yd per lb	Covers AWG (bare) wire
Class 4, Type 4PU:			
G17–I–1530–80	3/32	61	
G17–I–1530–140	1/8	45	9–10
G17–I–1530–200	3/16	30	
G17–I–1530–260	7/32	26	4–5
G17–I–1530–320	1/4	23	2–3
G17–I–1530–380	9/32	22.6	1–2
G17–I–1530–440	5/16	20	0–1
G17–I–1530–500	3/8	17	00–0
G17–I–1530–560	7/16	13	000–00

GLASS, BRAIDED (UNTREATED)
Spec: MIL-I-1140A Insulation Class C

Group GFU, Class CF. A heavy braided, glass-fiber sleeving which readily absorbs insulating varnish. Flexible with high mechanical strength. Suitable for insulating bare wire, leads, and rods.

Unit of issue: Yard Approximate cost: $0.10 per yard

Stock No.	ID, in.	Wall thickness, in.	Approx. yd per lb	Covers AWG (bare) wire
Group GFU, Class CF:				
G17-I-2644-700	1/16	0.0070	221	13-18
G17-I-2644-705	1/8	0.0090	100	9-10
G17-I-2644-710	3/16	0.0090	83	
G17-I-2644-715	1/4	0.0085	65	2-3
G17-I-2644-720	5/16	0.0085	52	0-1
G17-I-2644-725	3/8	0.0085	44	00-0
G17-I-2644-730	1/2	0.0075	32	000-00

BRAIDED FABRIC SLEEVING (VARNISHED)
Spec: MIL-I-3190 Insulation Class A

Class A-A-1. A braided cotton, rayon, or nylon fabric treated with a continuous film of oleoresinous varnish. It has high dielectric strength and good flexibility. Furnished in 3-foot lengths.

Unit of issue: Foot Approximate cost: $0.35 per foot

Stock No.	ID, in., min	For wire size, AWG
Class A-A-1:		
G17-I-1715-600	0.020	24
G17-I-1715-605	0.032	20
G17-I-1715-610	0.040	18
G17-I-1715-615	0.045	17
G17-I-1715-620	0.051	16
G17-I-1715-625	0.057	15
G17-I-1715-630	0.064	14
G17-I-1715-635	0.072	13
G17-I-1715-640	0.081	12
G17-I-1715-645	0.091	11
G17-I-1715-650	0.102	10
G17-I-1715-655	0.114	9
G17-I-1715-660	0.129	8
G17-I-1715-665	0.144	7
G17-I-1715-670	0.162	6
G17-I-1715-675	0.182	5
G17-I-1715-680	0.204	4
G17-I-1715-685	0.229	3
G17-I-1715-690	0.258	2
G17-I-1715-695	0.289	1
G17-I-1715-700	0.325	0
G17-I-1715-705	0.375	3/8 in.
G17-I-1715-710	0.438	7/16 in.
G17-I-1715-715	0.500	1/2 in.
G17-I-1715-720	0.625	5/8 in.
G17-I-1715-725	0.750	3/4 in.
G17-I-1715-730	0.875	7/8 in.
G17-I-1715-735	1.000	1 in.

Braided Glass Sleeving (Varnished)

Spec: MIL–I–3190 Insulation Class B

Class B–A–1. A braided glass fabric treated with a continuous film of oleoresinous varnish. It has high dielectric strength and good flexibility. Furnished in 3-foot lengths.

Unit of issue: Foot Approximate cost: $0.60 per foot

Stock No.	ID, in., min	For wire size, AWG
Class B–A–1:		
G17–I–2641–300	0.020	24
G17–I–2641–305	0.032	20
G17–I–2641–310	0.040	18
G17–I–2641–315	0.045	17
G17–I–2641–320	0.051	16
G17–I–2641–325	0.057	15
G17–I–2641–330	0.064	14
G17–I–2641–335	0.072	13
G17–I–2641–340	0.081	12
G17–I–2641–345	0.091	11
G17–I–2641–350	0.102	10
G17–I–2641–355	0.114	9
G17–I–2641–360	0.129	8
G17–I–2641–365	0.144	7
G17–I–2641–370	0.162	6
G17–I–2641–375	0.182	5
G17–I–2641–380	0.204	4
G17–I–2641–385	0.229	3
G17–I–2641–390	0.258	2
G17–I–2641–395	0.289	1
G17–I–2641–400	0.325	0
G17–I–2641–405	0.375	⅜ in.
G17–I–2641–410	0.438	7/16 in.
G17–I–2641–415	0.500	½ in.
G17–I–2641–420	0.625	⅝ in.
G17–I–2641–425	0.750	¾ in.
G17–I–2641–430	0.875	⅞ in.
G17–I–2641–435	1.000	1 in.

Braided Glass Sleeving (Silicone)

Spec: MIL–I–3190 Insulation Class H

Class H–A–1. A braided glass fabric treated with a continuous film of silicone varnish. It has high dielectric strength and good flexibility. Furnished in 3-foot lengths.

Unit of issue: Foot Approximate cost: $0.75 per foot

Stock No.	ID, in., min	For wire size, AWG
Class H–A–1:		
G17–I–2642–3200	0.020	24
G17–I–2642–3205	0.032	20
G17–I–2642–3210	0.040	18
G17–I–2642–3215	0.045	17
G17–I–2642–3220	0.051	16
G17–I–2642–3225	0.057	15
G17–I–2642–3230	0.064	14
G17–I–2642–3235	0.072	13
G17–I–2642–3240	0.081	12
G17–I–2642–3245	0.091	11
G17–I–2642–3250	0.102	10
G17–I–2642–3255	0.114	9
G17–I–2642–3260	0.129	8
G17–I–2642–3265	0.144	7
G17–I–2642–3270	0.162	6
G17–I–2642–3275	0.182	5
G17–I–2642–3280	0.204	4
G17–I–2642–3285	0.229	3
G17–I–2642–3290	0.258	2
G17–I–2642–3295	0.289	1
G17–I–2642–3300	0.325	0
G17–I–2642–3305	0.375	⅜ in.
G17–I–2642–3310	0.438	7/16 in.
G17–I–2642–3315	0.500	½ in.
G17–I–2642–3320	0.625	⅝ in.
G17–I–2642–3325	0.750	¾ in.
G17–I–2642–3330	0.875	⅞ in.
G17–I–2642–3335	1.000	1 in.

Synthetic Resin Sleeving

Spec: JAN–I–631 Insulation Class A
Form U, Flexible

Type A. A high-dielectric-strength, low-loss-factor, extruded sleeving. Intended primarily for high-frequency circuits. Polystyrene and polyethylene are typical materials of this type.

Type F, Grade A. A moderate-mechanical-strength, extruded sleeving with good electrical properties suitable as an alternate for rubber insulating tape in cable and other applications where sleeving may be used. Polyvinyl chloride and vinyl acetate are typical materials of this type.

Unit of issue: Foot Approximate cost: $0.07 per foot

Stock No.			Wall thickness, in.	ID, in.	For wire size, AWG
Black	Red	White			
Type A:					
G17–I–5797–100	G17–I–5797–165	G17–I–5797–220	0.020	0.042	18
G17–I–5797–102	G17–I–5797–167	G17–I–5797–222	0.020	0.053	16
G17–I–5797–104	G17–I–5797–169	G17–I–5797–224	0.020	0.066	14
G17–I–5797–106	G17–I–5797–171	G17–I–5797–226	0.020	0.085	12
G17–I–5797–108	G17–I–5797–173	G17–I–5797–228	0.020	0.106	10
G17–I–5797–110	G17–I–5797–175	G17–I–5797–230	0.020	0.118	9
G17–I–5797–112	G17–I–5797–177	G17–I–5797–232	0.020	0.133	8
G17–I–5797–114	G17–I–5797–179	G17–I–5797–234	0.020	0.148	7
G17–I–5797–116	G17–I–5797–181	G17–I–5797–236	0.020	0.166	6
G17–I–5797–118	G17–I–5797–183	G17–I–5797–238	0.020	0.186	5
Type A, transparent (clear):					
G17–I–5797–205	....	....	0.020	0.186	5

Stock No.	Wall thickness, in.	ID, in.	Cable size, cm
Type F, Grade A, Transparent (Clear)			
G17–I–5797–500	0.020	0.160	3,000
G17–I–5797–505	0.020	0.250	4,000
G17–I–5797–510	0.020	0.280	9,000
G17–I–5797–515	0.020	0.320	14,000
G17–I–5797–520	0.020	0.360	23,000
G17–I–5797–525	0.030	0.400	30,000
G17–I–5797–530	0.030	0.430	40,000
G17–I–5797–535	0.030	0.450	50,000
G17–I–5797–540	0.030	0.520	60,000
G17–I–5797–545	0.040	0.570	75,000
G17–I–5797–550	0.040	0.630	100,000
G17–I–5797–555	0.040	0.680	125,000
G17–I–5797–560	0.040	0.760	150,000
G17–I–5797–565	0.050	0.820	200,000
G17–I–5797–570	0.050	0.890	250,000
G17–I–5797–575	0.050	0.960	300,000
G17–I–5797–580	0.050	1.030	350,000
G17–I–5797–585	0.050	1.100	400,000
G17–I–5797–590	0.060	1.165	500,000
G17–I–5797–595	0.060	1.225	650,000
G17–I–5797–600	0.060	1.285	400,000
G17–I–5797–605	0.060	1.365	800,000
G17–I–5797–610	0.060	1.470	650,000
G17–I–5797–615	0.060	1.585	800,000

Stock No.	Wall thickness, in.	ID, in.	AWG wire size
Type F, Grade A, Transparent (Translucent)			
G17–I–5797–900	0.020	0.034	20
G17–I–5797–905	0.020	0.038	19
G17–I–5797–910	0.020	0.042	18
G17–I–5797–915	0.020	0.047	17
G17–I–5797–920	0.020	0.053	16
G17–I–5797–925	0.020	0.059	15
G17–I–5797–930	0.020	0.066	14
G17–I–5797–935	0.020	0.076	13
G17–I–5797–940	0.020	0.085	12
G17–I–5797–945	0.020	0.095	11
G17–I–5797–950	0.020	0.106	10
G17–I–5797–955	0.020	0.118	9
G17–I–5797–960	0.020	0.133	8
G17–I–5797–965	0.020	0.148	7
G17–I–5797–970	0.020	0.160	3,000 cm
G17–I–5797–975	0.020	0.166	6
G17–I–5797–985	0.020	0.208	4
G17–I–5797–995	0.020	0.234	3
G17–I–5797–1010	0.020	0.250	4,000 cm
G17–I–5797–1020	0.020	0.263	2
G17–I–5797–1030	0.020	0.294	1
G17–I–5797–1120	0.025	0.313	5/16 in.
G17–I–5797–1130	0.025	0.375	3/8 in.
G17–I–5797–1150	0.025	0.500	1/2 in.

Insulation, Electrical, Tubing

A rigid electrical insulation item consisting of a mandrel- or bar-wound plastic in built-up layers or a material compressed or formed into tubing. Usually circular, but may be square or other shape.

TUBING

HARD FIBRE
Spec: JAN–F–1148 Insulation Class O

Grade BH, Form T (*Bone Hard*). A high-density material of chemically gelled paper stock having excellent machining properties, arc resistance, and toughness.

Unit of issue: Foot Approximate cost: $0.35 per foot

Stock No.	ID, in.	OD, in.	Wall thickness, in.
Grade BH, Form T:			
G17–I–2504–950	1/8	3/16	1/32
G17–I–2505	1/8	1/4	1/16
G17–I–2505–150	1/8	5/16	3/32
G17–I–2514–9750	1/4	3/8	1/16
G17–I–2515	1/4	1/2	1/8
G17–I–2515–250	1/4	5/8	3/16
G17–I–2525	3/8	1/2	1/16
G17–I–2525–250	3/8	5/8	1/8
G17–I–2535	1/2	3/4	1/8
G17–I–2535–250	1/2	7/8	3/16
G17–I–2575	7/8	1	1/16
G17–I–2575–250	7/8	1 1/8	1/8
G17–I–2590	1	1 1/4	1/8
G17–I–2615	1 3/16	1 1/2	5/32
G17–I–2620	1 1/4	1 1/2	1/8

PASTED MICA (MOLDABLE)
Spec: HH–I–538 Insulation Class B

Class PM, Type PMM, Form T. A pasted-mica, round tubing of high dielectric strength. A thin protective paper is applied as a covering to the outside of the tubing.

Unit of issue: Foot Approximate cost: $0.30 per foot

Stock No.	ID, in.	OD, in.	Length, in.
Type PMM, Form T:			
G17–I–3900	1/8	1/4	12
G17–I–3910	1/8	5/16	12
G17–I–3920	1/4	3/8	12
G17–I–3930	5/16	7/16	24
G17–I–3950	3/8	1/2	24
G17–I–3970	1/2	5/8	24
G17–I–4000	5/8	3/4	24
G17–I–4010	5/8	3/4	36
G17–I–4020	1	1 1/8	36

LAMINATED
Spec: MIL–P–79 Insulation Class A

PAPER BASE

Type PBG, Form Tr. A general-purpose, paper-base, rolled tubing having fairly good mechanical and electrical properties but poor fire and arc resistance.

Unit of issue: Foot Approximate cost: $0.25 per foot

Type PBE, Form Tr. A general-purpose, paper-base, rolled tubing having fairly good mechanical strength, with good electrical properties for radio-frequency and high-humidity conditions. Poor fire and arc resistance.

Unit of issue: Foot Approximate cost: $0.30 per foot

GLASS BASE Insulation Class B

Type GMG, Form Tm. A general-purpose, glass-base, melamine resin molded tubing with high mechanical strength and fire- and arc-resisting characteristics.

Unit of issue: Foot Approximate cost: $1.50 per foot

Type GMG, Form Tr. A general-purpose, glass-base, melamine resin rolled tubing with high density, best mechanical strength, and fire- and arc-resistance characteristics.

Unit of issue: Foot Approximate cost: $2.00 per foot

Stock No.	Stock No.	ID, in.	OD, in.
Type PBG, Tr:	Type PBE, Tr:		
G17–I–5708	G17–I–5644	1/8	3/8
G17–I–5709	G17–I–5645	1/4	1/2
G17–I–5710	G17–I–5646	1/4	5/8
G17–I–5711	G17–I–5647	5/16	1/2
G17–I–5712	G17–I–5648	3/8	5/8
G17–I–5713	G17–I–5649	7/16	9/16
G17–I–5714	G17–I–5650	1/2	3/4
G17–I–5715	G17–I–5651	1/2	7/8
G17–I–5716	G17–I–5652	9/16	13/16
G17–I–5717	G17–I–5653	5/8	7/8
G17–I–5718	G17–I–5654	3/4	7/8
G17–I–5719	G17–I–5655	3/4	1
G17–I–5720	G17–I–5656	7/8	1 1/8
G17–I–5721	G17–I–5657	1	1 1/4
G17–I–5722	G17–I–5658	1 1/16	1 3/16
G17–I–5723	G17–I–5659	1 1/16	1 1/4
G17–I–5724	G17–I–5660	1 3/16	1 3/8
G17–I–5725	G17–I–5661	1 3/16	1 1/2
G17–I–5726	G17–I–5662	1 1/4	1 1/2
G17–I–5727	G17–I–5663	1 1/4	1 5/8
G17–I–5728	G17–I–5664	1 3/8	1 5/8
G17–I–5729	G17–I–5665	1 1/2	1 3/4
G17–I–5730	G17–I–5666	1 3/4	2

Stock No.	Stock No.	ID, in.	OD, in.
Type GMG, Tm:	Type GMG, Tr:		
G17–I–5765–300	G17–I–5765–600	1/4	3/8
G17–I–5765–310	G17–I–5765–610	1/4	1/2
G17–I–5765–320	G17–I–5765–620	1/4	5/8
G17–I–5765–330	G17–I–5765–630	3/8	1/2
G17–I–5765–340	G17–I–5765–640	3/8	5/8
G17–I–5765–350	G17–I–5765–650	1/2	3/4
G17–I–5765–360	G17–I–5765–660	1/2	7/8
G17–I–5765–370	G17–I–5765–670	7/8	1
G17–I–5765–380	G17–I–5765–680	7/8	1 1/8
G17–I–5765–400	G17–I–5765–690	1	1 1/4
G17–I–5765–425	G17–I–5765–720	1 3/16	1 1/2
G17–I–5765–445	G17–I–5765–730	1 1/4	1 1/2
G17–I–5765–450	G17–I–5765–740	1 1/4	1 5/8
	G17–I–5765–750	1 5/16	1 1/2
G17–I–5765–460	G17–I–5765–760	1 3/8	1 5/8
G17–I–5765–475	G17–I–5765–770	1 1/2	1 3/4
G17–I–5765–490	G17–I–5765–780	1 3/4	2
	G17–I–5765–790	1 13/16	2
	G17–I–5765–800	2	2 1/4
	G17–I–5765–810	2 1/4	2 1/2
	G17–I–5765–820	2 1/2	2 3/4
	G17–I–5765–830	2 3/4	3
	G17–I–5765–840	2 3/4	3 1/2

Insulation, Electrical, Mica

An electrical insulation consisting of natural mica in the form of blocks or splittings. When pasted or built up with binders or reinforcement, the composite mica structure should be classified as Insulation, sheet, tape, or tubing.

NATURAL MICA

MICA (MUSCOVITE)
Spec: HH–I–538 Insulation Class C

Class NM, Form S. Trimmed, uncut, natural mica in sheet form. Because of high cost and limited availability, only two types are shown here: type NMHs (heavily stained) and NMSt (stained). Where a higher quality type is required, justification for its use shall be furnished the Bureau concerned along with the request or requisition. Minimum dielectric strength, 1,000 volts per mil. Sheets are not less than 0.004 inch or more than 0.050 inch in thickness. Approximate weight, 0.101 pound per cubic inch.

Unit of issue: Pound Approximate cost: $3.00 per pound

Stock No.	Grade	Size rectangle		Stock No.	Grade	Size rectangle	
		Min area, sq in.	Min size, in.			Min area, sq in.	Min size, in.
Type NMHs (Heavily Stained):				Type NMSt (Stained):			
G17–I–3843	A–1	36	4.0	G17–I–3847	A–1	36	4.0
G17–I–3843–10	1	24	3.0	G17–I–3847–10	1	24	3.0
G17–I–3843–20	2	15	2.0	G17–I–3847–20	2	15	2.0
G17–I–3843–30	3	10	2.0	G17–I–3847–30	3	10	2.0
G17–I–3843–40	4	6	1.5	G17–I–3847–40	4	6	1.5
G17–I–3843–50	5	3	1.0	G17–I–3847–50	5	3	1.0
G17–I–3843–60	5½	2½	1.0	G17–I–3847–60	5½	2½	1.0
G17–I–3843–70	6	1	0.75	G17–I–3847–70	6	1	0.75

Insulation, Electrical, Film-thin

An electrical insulation item consisting of a nonreinforced synthetic plastic extrusion or shaved thin film usually less than $\frac{1}{16}$ inch thick and wider than 8 inches.

SYNTHETIC RESIN

Cellulose Acetate

Spec: JAN–I–631 Insulation Class A

Type C, Form S. A transparent, cellulose acetate, thin-film plastic intended for use as electrical insulation. Possesses good electrical properties, a fair degree of moisture resistance, fairly low loss factor, and a higher degree of fire resistance than most plastic film materials. Minimum dielectric strength, 7,800 volts. Furnished in rolls 30 inches wide, 20 yards long.

Unit of issue: Yard Approximate cost: $0.30 per yard

Stock No.	Thickness, in.
Type C, Form S:	
G17–I–5778–500	0.005

Insulation, Electrical, Liquid, Dielectric

An electrical insulation item consisting of a natural or synthetic resinous substance in liquid form having dielectric properties.

VARNISH

Insulating Varnish

Spec: JAN–V–1137 Insulation Class A

Type N. Material for application by Naval personnel.

Grade BA, black, air drying, insulating.
Grade BB, black, baking, insulating.
Grade CA, clear, air drying, insulating.
Grade CB, clear, baking, insulating.
Grade CF, clear, finishing.

The above grades of insulating varnish are suitable for application to the electrical windings and other parts of motors, generators, and transformers and to electrical apparatus in general. Grade CB, clear baking varnish, in most instances, gives maximum protection to the windings from moisture, oil, sea water, and other deleterious substances.

These grades are usually designated as class A insulation when applied over windings using resin-covered wire, cotton, or paper or similar insulation material. When the above grades of varnish are applied over windings using glass-served wire, with

glass, mica, asbestos, and other similar insulating materials, the resulting structure is designated as class B insulation.

Unit of issue: Gallon — Approximate cost: $2.00 per gallon

Stock No.	Container
Grade BA:	
G52–V–1100	1-gal can
G52–V–1105	5-gal can
Grade BB:	
G52–V–1145	1-gal can
G52–V–1150	5-gal can
Grade CA:	
G52–V–1240	1-pt can
G52–V–1255	1-gal can
G52–V–1260	5-gal can
Grade CB:	
G52–V–1300	1-gal can
G52–V–1305	5-gal can
Grade CF:	
G52–V–1345	1-gal can
G52–V–1350	5-gal can

INSULATING VARNISH (SILICONE)

Spec: (Refer to BuShips) — Insulation Class H

Type N. Material for application by Naval personnel.

Grade HTB, a high-temperature baking type of silicone varnish suitable for application to electrical windings. Bakes at temperature of 250 C (482 F). Two grades, Dow Corning Corporation DC993 and General Electric Company 9989–1, are available. These varnishes should not be mixed together, as precipitation may occur.

Grade LTB, a low-temperature baking type of silicone varnish suitable for application to electrical windings. Bakes at temperature of 150 C (302 F). One grade, Dow Corning Corporation DC996, is available.

Unit of issue: Gallon — Approximate cost: $12.00 per gallon

Stock No.	Container
Grade HTB–993:	
G52–V–1361–10	1-gal can
G52–V–1361–20	5-gal can
G52–V–1361–100	55-gal drum
Grade HTB–9989–1:	
G52–V–1361–510	1-gal can
G52–V–1361–520	5-gal can
G52–V–1361–600	55-gal drum
Grade LTB–996:	
G52–V–1360–10	1-gal can
G52–V–1360–20	5-gal can
G52–V–1360–100	55-gal drum

Wire, Magnet, Insulated

A solid copper conductor, usually round, of small diameter, and insulated with a synthetic resin or a fibrous filler material combined with a resin.

MAGNET WIRE, ROUND, RESIN-COVERED

Spec: JAN–W–583 — Insulation Class A

Type R, Single. A solid conductor insulated with one coat of insulating resin.

Type R2, Double. A solid copper conductor insulated with two coats of insulating resin.

Type R4, Quadruple. A solid copper conductor insulated with four coats of insulating resin.

Unit of issue: Pound — Approximate cost: $0.40 to $1.70 per pound

Stock No.	Wire size, AWG	Ft per lb
Type R, Single:		
G15–W–62018	40	32,600
G15–W–62019	39	25,800
G15–W–62020	38	20,500
G15–W–62021	37	16,296
G15–W–62022	36	12,850
G15–W–62023	35	10,200
G15–W–62024	34	8,160
G15–W–62025	33	6,430
G15–W–62026	32	5,120
G15–W–62027	31	4,050
G15–W–62028	30	3,220
G15–W–62029	29	2,550
G15–W–62030	28	2,030
G15–W–62031	27	1,610
G15–W–62050	26	1,280
G15–W–62055	25	1,010
G15–W–62060	24	805
G15–W–62065	23	639
G15–W–62070	22	507
G15–W–62075	21	402
G15–W–62080	20	319
G15–W–62085	19	256
G15–W–62090	18	201
G15–W–62095	17	159
G15–W–62100	16	127
G15–W–62110	15	99.9
G15–W–62115	14	78.6
G15–W–62120	13	63.0
G15–W–62125	12	50.0
G15–W–62130	11	39.8
G15–W–62135	10	31.5
G15–W–62140	9	25.2
G15–W–62145	8	20.0

Stock No.	Wire size, AWG	Ft per lb
Type R2, Double:		
G15–W–59250	40	31,700
G15–W–59275	39	25,200
G15–W–59280	38	20,100
G15–W–59285	37	15,900
G15–W–59290	36	12,650
G15–W–59295	35	10,050
G15–W–59300	34	7,940
G15–W–59305	33	6,330
G15–W–59310	32	5,050
G15–W–59315	31	3,990
G15–W–59320	30	3,160
G15–W–59325	29	2,520
G15–W–59330	28	2,000
G15–W–59335	27	1,580
G15–W–59500	26	1,260
G15–W–59505	25	1,000
G15–W–59510	24	794
G15–W–59520	23	633
G15–W–59525	22	503
G15–W–59530	21	398
G15–W–59535	20	315
G15–W–59540	19	253
G15–W–59545	18	200
G15–W–59550	17	158
G15–W–59555	16	126
G15–W–59560	15	99.5
G15–W–59565	14	79.4
G15–W–59570	13	62.9
G15–W–59575	12	50.0
G15–W–59580	11	39.7
G15–W–59585	10	31.4
G15–W–59590	9	25.2
G15–W–59595	8	19.8
Type R4, Quadruple:		
G15–W–62015–100	23	612
G15–W–62015–110	22	491
G15–W–62015–120	21	389
G15–W–62015–130	20	310
G15–W–62015–140	19	247
G15–W–62015–150	18	197
G15–W–62015–160	17	156
G15–W–62015–170	16	124
G15–W–62015–180	15	98.6

MAGNET WIRE, ROUND, COTTON-COVERED

Spec: JAN–W–583 Insulation Class A

Type C, Single. A solid copper conductor insulated with a single serving of cotton yarn.

Type C2, Double. A solid copper conductor insulated with two servings of cotton yarn with each ply of yarn served in opposite directions.

Unit of issue: Pound Approximate cost: $0.27 to $3.40 per pound

Stock No.	Wire size, AWG	Ft per lb
Type C, Single:		
G15–W–63035	40	20,400
G15–W–63040	39	17,500
G15–W–63045	38	14,900
G15–W–63050	37	12,000
G15–W–63055	36	10,100
G15–W–63060	35	8,330
G15–W–63065	34	6,900
G15–W–63070	33	5,470
G15–W–63075	32	4,470
G15–W–63080	31	3,630
G15–W–63085	30	2,930
G15–W–63090	29	2,340
G15–W–63095	28	1,870
G15–W–63100	27	1,505
G15–W–63105	26	1,210
G15–W–63110	25	972
G15–W–63115	24	775
G15–W–63120	23	617
G15–W–63125	22	493
G15–W–63130	21	392
G15–W–63135	20	312
G15–W–63140	19	249
G15–W–63145	18	197
G15–W–63150	17	157
G15–W–63155	16	125
G15–W–63160	15	99
G15–W–63165	14	78.8
G15–W–63170	13	62.5
G15–W–63175	12	49.8
G15–W–63180	11	39.6
G15–W–63185	10	31.5
G15–W–63190	9	25.0
G15–W–63195	8	19.8
G15–W–63200	7	15.7
G15–W–63205	6	12.5
G15–W–63210	5	9.90
G15–W–63215	4	7.88

Stock No.	Wire size, AWG	Ft per lb
Type C2, Double:		
G15–W–59020	36	7,750
G15–W–59025	35	6,620
G15–W–59030	34	[illegible]
G15–W–59035	33	4,570
G15–W–59040	32	[illegible]
G15–W–59045	31	[illegible]
G15–W–59050	30	2,570
G15–W–59055	29	[illegible]
G15–W–59060	28	[illegible]
G15–W–59065	27	1,385
G15–W–59070	26	[illegible]
G15–W–59075	25	[illegible]
G15–W–59080	24	[illegible]
G15–W–59085	23	585
G15–W–59090	22	470
G15–W–59095	21	376
G15–W–59100	20	301
G15–W–59105	19	240
G15–W–59110	18	192
G15–W–59115	17	155
G15–W–59120	16	122
G15–W–59125	15	[illegible]
G15–W–59130	14	[illegible]
G15–W–59135	13	61.7
G15–W–59140	12	[illegible]
G15–W–59145	11	[illegible]
G15–W–59150	10	[illegible]
G15–W–59155	9	24.7
G15–W–59160	8	19.6
G15–W–59165	7	15.6
G15–W–59170	6	12.4
G15–W–59175	5	9.80
G15–W–59180	4	[illegible]
G15–W–59185	3	6.17
G15–W–59190	2	4.92
G15–W–59195	1	[illegible]
G15–W–59200	0	[illegible]

MAGNET WIRE, ROUND, GLASS-COVERED

Spec: JAN–W–583 Insulation Class B

Type GV, Single. A solid copper conductor insulated with a single serving of glass yarn and impregnated with organic varnish.

Type G2V, Double. A solid copper conductor insulated with two servings of glass yarn with each ply of yarn served in opposite directions and impregnated with organic varnish.

Unit of issue: Pound

Approximate cost: $0.52 to $1.50 per pound

Stock No.	Wire size, AWG	Ft per lb
Type GV, Single:		
G15–W–63240–38	25	935
G15–W–63240–40	24	752
G15–W–63240–42	23	588
G15–W–63240–44	22	474
G15–W–63240–46	21	380
G15–W–63240–48	20	305
G15–W–63240–50	19	245
G15–W–63240–52	18	195
G15–W–63240–54	17	154
G15–W–63240–56	16	123
G15–W–63240–58	15	99.0
G15–W–63240–60	14	78.1
G15–W–63240–62	13	62.1
G15–W–63240–64	12	49.5
G15–W–63240–66	11	39.3
G15–W–63240–68	10	31.2
G15–W–63240–70	9	24.8
G15–W–63240–72	8	19.6
Type G2V, Double:		
G15–W–59225	25	870
G15–W–59226	24	710
G15–W–59227	23	550
G15–W–59228	22	446
G15–W–59229	21	362
G15–W–59230	20	293
G15–W–59231	19	236
G15–W–59232	18	189
G15–W–59233	17	149
G15–W–59234	16	120
G15–W–59235	15	96.2
G15–W–59236	14	77.0
G15–W–59237	13	61.0
G15–W–59238	12	48.6
G15–W–59239	11	38.8
G15–W–59240	10	30.8
G15–W–59241	9	24.5
G15–W–59242	8	19.4

MAGNET WIRE, ROUND, GLASS-COVERED (SILICONE)
Spec: MIL–W–16072 (Ships) Insulation Class H

Type GH, Single. A solid copper conductor insulated with a single serving of glass yarn and impregnated with a high-temperature silicone varnish.

Type G2H, Double. A solid copper conductor insulated with a double serving of glass yarn and impregnated with a high-temperature silicone compound.

Unit of issue: Pound

Approximate cost: $0.80 to $3.60 per pound

Stock No.	Wire size, AWG	Ft per lb
Type GH, Single:		
G15–W–63235–50	36	9,060
G15–W–63235–70	34	6,180
G15–W–63235–90	32	4,160
G15–W–63235–110	30	2,717
G15–W–63235–120	29	2,214
G15–W–63235–130	28	1,772
G15–W–63235–140	27	1,411
G15–W–63235–150	26	1,140
G15–W–63235–160	25	935
G15–W–63235–170	24	752
G15–W–63235–180	23	588
G15–W–63235–190	22	474
G15–W–63235–200	21	380
G15–W–63235–210	20	305
G15–W–63235–220	19	245
G15–W–63235–230	18	195
G15–W–63235–240	17	154
G15–W–63235–250	16	123
G15–W–63235–260	15	99.0
G15–W–63235–270	14	78.1
Type G2H, Double:		
G15–W–59212–130	26	1,060
G15–W–59212–140	25	870
G15–W–59212–150	24	710
G15–W–59212–160	23	550
G15–W–59212–170	22	446
G15–W–59212–180	21	362
G15–W–59212–190	20	293
G15–W–59212–200	19	236
G15–W–59212–210	18	187
G15–W–59212–220	17	149
G15–W–59212–230	16	120
G15–W–59212–240	15	96.2
G15–W–59212–250	14	77.0
G15–W–59212–260	13	61.0
G15–W–59212–270	12	48.6

Appendix II. ELECTRICAL INSULATING MATERIALS–PROPERTIES AND TEST INFORMATION

This appendix has been prepared to give essential characteristics of materials and test information to permit evaluation and application. It has been prepared for the purpose of assisting shop personnel in the selection of the correct insulating materials for the maintenance and repair of electrical equipment.

All materials have been taken from Appendix I and cover the important properties of each material.

As this appendix is to be used only as a guide and for ready reference purposes, the final selections of material should be based on the information available from the latest edition of the applicable specifications.

It should be considered that the property values listed herein are intended primarily to ensure controlling the quality of the materials purchased and should not be directly used to predict the performance of the material in actual service equipment. If there is any doubt in the mind of the shop personnel as to what material to use, refer to Chap. 3.

CONDITIONING

1. *Nomenclature.* The following letters are used to indicate the respective general conditioning procedures:

Condition A—As received, no special conditioning

Condition B—Reference condition, 24 hours in oven at 100 C

Condition C—Humidity conditioning

Condition D—Immersion conditioning in distilled water

Condition E—Temperature conditioning

2. *Designation.* *a.* Conditioning procedures are designated as follows:

First: A capital letter indicating the general condition of the specimen, *i.e.*, as received, reference, humidity, immersion, and temperature conditioning.

Second: A number indicating in hours the duration of the conditioning.

Third: A number indicating in degrees centigrade the conditioning temperature.

Fourth: A number indicating relative humidity, whenever relative humidity is controlled. (NOTE. Relative humidity obtained over calcium chloride is taken as zero.)

The numbers are separated from each other by slant marks, and from the capital letter by a dash.

b. Examples:

Condition C–48/50/0—Humidity condition, 48 hours at 50 C over calcium chloride (zero percent relative humidity).

Condition C–96/25/70—Humidity condition 96 hours at 25 C and 70 percent relative humidity.

Condition D–6/100—Immersion condition, 6 hours in distilled water at 100 C (boiling water, not less than 96 C).

Condition E–2/−23—Temperature condition, 2 hours at −23 C.

Nominal thickness, in.	Max % water absorption, 2 hr		Min dielectric strength, volts per mil		Min tensile strength, psi				Min flexural strength, psi			
					BH		CH		BH		CH	
	BH	CH	BH	CH	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise	Cross-wise	Length-wise
1/32	50	55	175	175	6,500	8,500	6,000	8,000				
1/16	50	55	175	175	6,500	8,500	6,000	8,000				
3/32	50	55	150	150	6,500	8,500	6,000	8,000				
1/8	50	55	150	150	6,000	8,000	5,500	8,000	13,000	15,000	12,000	14,000
3/16	20	25	100	100	6,000	8,000	5,500	7,500	13,000	15,000	12,000	14,000
1/4	20	25	100	100	6,000	8,000	5,500	7,500	13,000	15,000	12,000	14,000
3/8	20	25	100	100	6,000	8,000	5,500	7.500	13,000	15,000	12,000	14,000
1/2	10	15	50	50	6,000	8,000	5,500	7,500	13,000	15,000	12,000	14,000
5/8	. .	15	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
3/4	. .	15	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
7/8	. .	15	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
1	. .	8	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
1 1/8	. .	8	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
1 1/4	. .	8	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
1 1/2	. .	8	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
1 3/4	. .	8	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000
2	. .	8	...	...	....	....	5,000	7,000	.....	.....	11,000	13,000

LAMINATES

PAPER BASE, TYPE PBE, TYPE PBG
Spec: MIL–P–3115A Insulation Class A
FABRIC BASE, TYPE FBG
Spec: MIL–P–3114A Insulation Class A

Test	Unit	Condition	PBE*	PBG*	FBG*
Dielectric strength, parallel laminations	Kv	D–48/50	6.0	5.0	3.5
Impact strength, edge loaded	Ft-lb per in.	E–48/50	0.40	0.50	2.20
Flexural strength, flat loaded	Psi	A	15,000	12,000	17,000
Water absorption	%	D–24/25	0.95	1.30	1.25
Dielectric constant, 1 megacycle	....	D–24/25	6.0	6.0	6.5
Power factor, 1 megacycle	....	D–24/25	0.05	0.05	0.10
Arc resistance	Sec	A	6	6	6
Flame resistance	....	A	Poor	Poor	Poor

* 1/8-in. material.

GLASS BASE, TYPE GMG
Spec: MIL–P–15037 Insulation Class B

GLASS BASE, TYPE GSG
Spec: MIL–P–997 Insulation Class H

Insulation, Electrical, Cloth

CLOTH

Cotton Fabric (Untreated), Type CFU

Spec: MIL–I–3042 Insulation Class O

	Breaking strength, lb per in.
Fill	38
Warp	50

Glass-fiber Cloth (Untreated), Type GFU

Spec: JAN–I–1140 Insulation Class C

Cloth No.	Thickness, in.	Breaking strength, lb per in.	
		Warp	Fill
Class CF (Continuous Filament):			
108	0.002	70	40
113	0.003	100	70
128	0.007	250	200
141	0.010	400	290
164	0.015	500	450
Class SF (Staple Fiber):			
261	0.015	170	110
294	0.023	180	200

Varnished Cambric

Spec: 17–C–8 Insulation Class A

Tensile strength:	
Fill	25 lb per in.
Warp	45 lb per in.
Tearing strength:	
0.007	200 g
0.010	250 g
Dielectric strength, short time	
E–96/25	1,200 volts per mil
C–96/25/96	400 volts per mil

Asbestos Fabric (Untreated)

Spec: MIL–I–3053 Insulation Class C

Type 4*PU*

Type 4*RU*

Thickness, in.	Tensile strength, lb per in.		Dielectric strength, volts per mil
	Warp	Fill	
0.025	30	25	25
0.035	50	32.5	25
0.045	70	32.5	25

Varnished Glass Cloth

Spec: 17–I–45 Insulation Class B

Silicone Glass Cloth

Spec: 17–I–45 Insulation Class H

Thickness, in.	Tensile strength, C–96/25/96		Dielectric strength, C–96/25/96, volts	Power factor, C–96/25/96, 60-cycle	Dielectric constant C–96/25/96, 60-cycle
	Warp	Fill			
Type GFV, Grade O, Varnished Glass					
0.005	100	70	2,500	0.25	6.0
0.007	100	70	4,400	0.25	6.0
0.010	150	100	5,500	0.25	6.0
0.012	250	200	6,000	0.25	6.0
Type GFV, Grade S, Silicone Glass					
0.004	70	35	1,800	0.15	4.2
0.007	100	70	3,500	0.15	4.2
0.010	150	100	4,000	0.15	4.2
0.012	250	200	4,000	0.15	4.2

	Thickness, in.	Width, in.	Breaking strength, lb per in.
Class SFM	0.010	½	79
		¾	114
		1	150
		1½	229
	0.015	½	118
		¾	169
		1	237
		1½	372
	0.020	½	182
		¾	260
		1	364
		1½	572
	0.025	½	215
		¾	307
		1	430
		1½	675

Glass Tape (Varnished)
Spec: 17-I-45 Insulation Class B
Group GFV, Grade O, Form T

Thickness, in.	Tensile strength, lb per in. C-96/25/96	Dielectric strength, C-96/25/96
0.005	100	2,500
0.007	100	4,400
0.010	150	5,500
0.012	250	6,000

Silicone Glass Tape
Spec: 17-I-45 Insulation Class H
Group GFV, Grade S, Form T

Thickness, in.	Tensile strength, lb per in. C-96/25/96	Dielectric strength, C-96/25/96
0.004	70	1,800
0.007	100	3,500
0.010	150	4,000
0.012	250	4,000

Mica-Glass Combinations
Spec: 17-I-62 Insulation Classes B and H
Type GMG
Type MG
Type PMG

Thickness, in.	Tensile strength, lb per in., C-96/25/0	Dielectric strength, C-96/25/96	Flexural strength, C-96/25/50
Class B:			
0.007	65	1,890	½
Class H:			
0.0035	40	840	½
0.007	65	1,680	½
0.010	90	2,400	½

Asbestos Tape (Untreated)
Spec: MIL-I-3053 Insulation Class C
Class 4, Type 4PU

Thickness, in.	Breaking strength, lb		Dielectric strength, volts per mil
	As received	5 min at 300 C	
0.015	30	12	25
0.020	35	15	25
0.025	50	18	25
0.030	85	30	25

Synthetic Fiber, Woven (Untreated)
Spec: 17-I-34 Insulation Class O
Group SFU, Form T
Type HMHR
Type MMHR

Thickness, in.	Breaking strength, lb per in.		Flexibility (cycles)	
	MMHR	HMHR	MMHR	HMHR
0.002	6	10	100	700
0.003	10	18	100	700
0.004	15	25	3,000	20,000
0.005	20	35	3,000	20,000
0.007	30	55	3,000	20,000
0.008	35	65	3,000	20,000
0.010	40	85	16,000	100,000
0.015	50	135	16,000	100,000
0.020	50	180	16,000	100.000
0.025	50	230	16,000	100,000

SYNTHETIC FIBER, WOVEN (TREATED)
Spec: 17–I–46 Insulation Class A
Group SFT, Form T

Thickness, in.	Tensile strength, lb per in. C–96/25/50	Tearing strength, g per sheet, C–96/25/50	Dielectric strenth, volts per mil, C–96/25/96
0.003	18	60	400
0.004	. .	. .	400
0.005	25	75	400

SYNTHETIC RESIN
Spec: JAN–I–631 Insulation Class A
Type F, Grade A, Form T

Dielectric breakdown, C–96/25/0, kv....	7.6
Tensile strength, C–96/25/50, psi.......	1,800
Elongation, C–96/25/50, % max.......	45×10^2
Return, C–96/25/50, % min..........	75
Soft temperature, C–96/25/50, °C min...	75

SYNTHETIC RESIN (ADHESIVE)
Spec: 17–T–28 Insulation Class A
Type VF

Thickness, C–96/25/50, in................	0.010
Tensile strength, C–96/25/50, lb per in. width	20
Adhesion, C–96/25/50, oz per in. width....	15
Dielectric strength, C–96/25/50, volts......	7,600
Breakdown, C–96/25/96.................	6,100
Penetration, C–96/25/50, °C..............	75

Insulation, Electrical, Rod

FIBRE

FIBRE RODS
Spec: JAN–F–1148 Insulation Class O
Grade BH, Form R
Grade CH, Form R

Nominal diameter, in.	% water absorbed in 2 hr		Tensile strength, psi		Flexural strength, psi	
	BH	CH	BH	CH	BH	CH
3/32	50	. .	8,000			
1/8	50	. .	8,000	.....	15,000	
3/16	35	. .	8,000	.....	15,000	
1/4	15	. .	8,000	.....	15,000	
5/16	15	. .	8,000	.....	15,000	
3/8	15	. .	8,000	.....	15,000	
1/2	15	. .	8,000	.....	15,000	
5/8	. .	10	.....	7,000	......	13,000
3/4	. .	10	.....	7,000	......	13,000
7/8	. .	10	.....	7,000	......	13,000
1	. .	10	.....	7,000	......	13,000
1 1/8	. .	8	.....	7,000	......	13,000
1 1/4	. .	8	.....	7,000	......	13,000
1 1/2	. .	8	.....	7,000	......	13,000
1 3/4	. .	8	.....	7,000	......	13,000
2	. .	8	....	7,000	......	13,000

PLASTICS

Plastic Rods
Spec: MIL–P–79
Type PBG, Form R — Insulation Class A
Type FBE, Form R — Insulation Class A
Type GMG, Form R — Insulation Class B

	Condition	Diameter, in.	PBG	FBE	GMG
Water absorption, % max	E–1/105	1/8–3/16	2.2		
		1/4–7/16	1.5	1.2	3.8
		1/2–1	1.0	0.90	2.5
	D–24/23	1–2	1.3	1.1	3.3
Compressive strength, axially, psi	A	1/8–3/16	20,000		
		1/4–2	20,000	21,000	22,000
Flexural strength, psi	A	1/8–3/16	15,000		
		1/4–1	15,000	12,000	35,000
		1–2	12,000	9,000	30,000
Specific gravity	A	1/8–3/16	1.30		
		1/4–2	1.30	1.26	1.80

Insulation, Electrical, Cordage

GLASS FIBER

Twisted Cord
Spec: MIL–I–1140A
Group GFU, Class CF — Insulation Class C

Average diam, in.	Average yd per lb	Average breaking strength, lb
1/64	3,640	15
1/32	760	60
3/64	435	90
1/16	210	165
5/64	165	200
3/32	140	210
1/8	90	260

Insulation, Electrical, Sleeving

SLEEVING

COTTON, BRAIDED (UNTREATED)
Spec: MIL–I–3042 Insulation Class O
Type CFU

Size No., in.	Nominal size, in.	Min yd per lb	Starch, max %
1/32	0.031	720	5
1/16	0.064	280	5
5/64	0.081	250	5
1/8	0.128	225	5
5/32	0.162	125	5
7/32	0.204	100	5
1/4	0.258	80	5
9/32	0.289	75	5
5/16	0.325	65	5
3/8	0.375	60	5
7/16	0.438	50	5

ASBESTOS, BRAIDED (UNTREATED)
Spec: MIL–I–3053 Insulation Class C
Class 4, *Type* 4PU (*Plain, Untreated*)

Asbestos content, % min 80
Dielectric strength, volts per mil 25
Wall thickness, in. .... 0.031 +0.016 –0.008

GLASS, BRAIDED (UNTREATED)
Spec: MIL–I–1140A Insulation Class C
Group GFU, Class CF

Glass .... Heavy: ECC–A
Wall thickness, in. .... 0.008 ±0.002

BRAIDED FABRIC SLEEVING (VARNISHED)
Spec: MIL–I–3190 Insulation Class A
Class A–A–1

Test	Unit	Condition	Value
Dielectric strength.....	Volts M.A.*	C–48/25/50	7,000
	Volts M.I.*	C–48/25/50	5,000
	Volts M.A.*	C–96/25/96	2,100
	Volts M.I.*	C–96/25/96	1,500
Oil immersion........	....	48 hr at 105 C	No swelling
Heat endurance.......	....	15 min at 218 C	No blisters
Heat aging...........	....	E–96/105	180 C
Burning rate.........	Sec per in.	C–48/25/50	45

* M.A. = average maximum volts to puncture; M.I. = minimum individual volts to puncture.

BRAIDED GLASS SLEEVING (VARNISHED)
Spec: MIL–I–3190 Insulation Class B
Class B–A–1

Test	Unit	Condition	Value
Dielectric strength.....	Volts M.A.*	C–48/25/50	7,000
	Volts M.I.*	C–48/25/50	5,000
	Volts M.A.*	C–96/25/96	2,800
	Volts M.I.*	C–96/25/96	2,000
Oil immersion........	....	48 hr at 105 C	No swelling
Heat endurance.......	....	15 min at 218 C	No blisters
Heat aging...........	....	E–96/105	180 C
Burning rate.........	Sec per in.	C–48/25/50	45

* M.A. = average maximum volts to puncture; M.I. = minimum individual volts to puncture.

Braided Glass Sleeving (Silicone)
Spec: MIL–I–3190 Insulation Class H
Class H–A–1

Test	Unit	Condition	Value
Dielectric strength.....	Volts M.A.*	C–48/25/50	7,000
	Volts M.I.*	C–48/25/50	5,000
	Volts M.A.*	C–96/25/96	2,800
	Volts M.I.*	C–96/25/96	2,000
Heat aging...........	....	E–96/195	180 C
Burning rate.........	Sec per in.	C–48/25/50	45

* M.A. = average maximum volts to puncture; M.I. = minimum individual volts to puncture.

Synthetic Resin Sleeving
Spec: JAN–I–631 Insulation Class A
Form U, Flexible
Type A
Type F, Grade a

Test	Condition	Unit	Nom. size	Type A	Type F, a
Dielectric strength...	C–96/25/0	Kv	0.020	22.5	13.6
	C–96/25/0	Kv	0.025	...	15.6
	C–96/25/0	Kv	0.025	...	15.6
	C–96/25/0	Kv	0.030	...	17.6
	C–96/25/0	Kv	0.040	...	20.6
	C–96/25/0	Kv	0.050	...	22.8
	C–96/25/0	Kv	0.060	...	24.0
Dissipation factor:					
1 kilocycle........	C–96/25/96	Max	....	0.0008	0.16
1 megacycle......	C–96/25/96	Max	....	0.0008	
Dielectric constant:					
1 kilocycle........	C–96/25/96	Max	....	2.7	8.0
1 megacycle......	C–96/25/96	Max	....	2.7	
Volume resistivity...	C–96/25/96	Ohm-cm	....	1×10^{16}	1×10^{10}
Tensile strength.....	C–96/25/50	Psi	....	1,400	1,800
Elongation.........	C–96/25/50	% (min)	....	3.5×10^2	2.0×10^2
	C–96/25/50	% (max)	....	.....	4.5×10^2
	E–400/100	% change	....	.....	35
Return.............	C–96/25/50	% (min)	0.020	.....	60
	C–96/25/50	% (min)	0.025		
	C–96/25/50	% (min)	0.025	.....	50
	C–96/25/50	% (min)	0.040	.....	45
	C–96/25/50	% (min)	0.050	.....	45
	C–96/25/50	% (min)	0.060	.....	45
Soft temperature....	C–96/25/50	°C	....	65	75
Shrinkage (length)...	E–2/100	% (max)	....	2.0	10.0

Insulation, Electrical, Tubing

TUBING

Fibre
Spec: JAN–F–1148 Insulation Class O
Grade BH, Form T
Grade CH, Form T

Nominal wall thickness, in.	Water absorption, 2 hr, % (max)		Dielectric strength, volts per mil (min)		Tensile strength, psi (length)	
	Grade BH	Grade CH	Grade BH	Grade CH	Grade BH	Grade CH
Up to 1/16	50	50	175	175	6,500	6,500
Over 1/16–1/8	50	50	150	150	6,500	6,500
Over 1/8–1/4	20	20	100	100	6,500	6,500
Over 1/4–5/16	10	10	50	50	6,500	6,500

Pasted Mica (Moldable)
Spec: HH–I–538 Insulation Class B
Class PM, Type PMM, Form T

Requirement	Limit	Value
Mica content....	Up to 1/4 in. ID	73%
	Over 1/4 in. ID	78%
Dielectric.......	Up to 1/7 in. wall thickness and over 1/4 in. ID	350 volts per mil, step by step 525 volts per mil, short time
	Over 1/8 in. wall thickness and up to 1/4 in. ID	275 volts per mil, step by step 450 volts per mil, short time
Tolerances......	Length	± 1/2 in.
	Inside diameter	+0.005–0.003 in.
	Outside diameter	±0.010 in.

LAMINATED TUBING (PLASTIC)
Spec: MIL–P–79 Insulation Class A
PAPER BASE
Type PBG, Form Tr
Type PBE, Form Tr

Spec: MIL–P–79 Insulation Class B
GLASS BASE
Type GMG, Form Tm
Type GMG, Form Tr

Test	Unit	Condition	Range, in.	PBG Tr	PBE Tr	GMG Tm	GMG Tr
Water absorption.....	%	E–1/105	Under 1/16–1/32 wall thickness	3.75	3.75		
		D_1–24/23	Under 1/8–1/16 wall thickness	3.00	3.00	4.50	4.50
			Under 1/4–1/8 wall thickness	2.40	2.40	3.60	3.60
			Under 1/2–1/4 wall thickness	2.00	2.00	2.90	2.90
			1–1/2 wall thickness	1.60	1.60	2.35	2.35
Dielectric strength, perpendicular to laminations, short time	Volts per mil	A	1/32 wall thickness	560	700		
			Over 1/32–1/16 wall thickness	400	500	175	175
			Over 1/16–1/8 wall thickness	280	350	130	130
			Over 1/8–1/4 wall thickness	200	250	85	85
			Over 1/4–1/2 wall thickness	140	175	65	65
			Over 1/2–1 wall thickness	100	125	45	45
Compressive strength, axially	Psi	A	All sizes up to and including 2 in. OD	12,000	11,000	18,000	13,000
Specific gravity......	......	A	All sizes	1.10	1.10	1.75	1.90

Insulation, Electrical, Mica

NATURAL MICA

MICA (MUSCOVITE)
Spec: JAN–I–1139 Insulation Class C
Class NM, Form S
Type NMHs
Type NMSt

Test	Unit	Limit	NMHs	NMSt
Dielectric strength, short time	Volts per mil	Average	1,500	1,500
		Minimum	1,000	1,000

Insulation, Electrical, Film-thin

SYNTHETIC RESIN

CELLULOSE ACETATE
Spec: JAN-I-631 Insulation Class A
Type C, Form S

Test	Condition	Unit	Thickness, in.	Type C
Dielectric strength	C-96/25/0	Kv	0.005	7.8
Dissipation factor:				
1 kilocycle	C-96/25/96	Max	....	0.045
1 megacycle	C-96/25/96	Max	....	0.07
Dielectric constant:				
1 kilocycle	C-96/25/96	....	....	8.0
1 megacycle	C-96/25/96	....	....	7.0
Volume resistivity	C-96/25/96	Ohms-cm	....	1×10^{12}
Tensile strength	C-96/25/50	Psi	....	6,000
Elongation	C-96/25/50	% (min)	....	10
	C-96/25/50	% (max)	....	50
Return	C-96/25/50	% (min)		
Soft temperature	C-96/25/50	°C	....	160
Shrinkage (length)	E-2/100	% (max)	....	3.0

Insulation, Electrical, Liquid, Dielectric

VARNISH

INSULATING VARNISH (ORGANIC)
Spec: JAN-V-1137 Insulation Class A
Type N
Grade BA
Grade BB
Grade CA
Grade CB
Grade CF

Requirement	BA	BB	CA	CB	CF
Flash point (min), °C	25	25	25	25	25
Nonvolatile, % (min)	40	50	40	50	40
Drying time, hr (max)	8	10	8	10	8
Consistency filament threads, mils:					
Max	2.00	2.00	2.00	2.00	2.00
Min	0.90	0.90	0.90	0.90	0.90
Difference in film thickness, % (max)	100	100	100	100	100
Sulfonation residue, % (min)	80	80	80	80	80
Benzene, % (max)	1.00	1.00	1.00	1.00	1.00
Methanol, % (max)	0	0	0	0	0
Ethanol, % (max)	0	0	0	0	0
Dielectric strength:					
Wet, volts per mil (min)	300	450	325	550	350
Dry, volts per mil (min)	600	1,067	667	1,067	667
Acidproofness, hr (min)	200	240	200	240	300
Sea-waterproofness, hr (min)	200	240	200	240	300
Flexibility, heat endurance, hr (min)	300	500	200	500	100

INSULATING VARNISH (SILICONE)
Spec: (Refer to BuShips) Insulation Class H
Type N
Grade HTB–993
Grade HTB–9989–1
Grade LTB–996

Requirement	HTB–993	HTB–9989–1	LTB–996
Nonvolatile, % (min)	50	50	50
Specific gravity at 25 C	1.01–1.02	..	1.01–1.02
Viscosity at 25 C, sec	30–70	..	30–70
Weight loss at 250 C, hr (min)	12	..	8*
Dielectric strength:			
Dry, volts per mil	800	..	800
Wet, volts per mil (min)	300	..	300
Crazing resistivity aged, 250 C, hr (min)	200	..	200
Cold-checking temperature, °C	–55	..	–55

* Weight loss at 150 C.

Wire, Magnet, Insulated

MAGNET WIRE, ROUND, RESIN-COVERED
Spec: JAN-W-583 Insulation Class A
Type R
Type R2
Type R4

Requirement	Unit	Condition	Sizes	Type		
				R	R2	R4
Dielectric strength (layer)	Volts per mil	C-96/25/50	All	1,000	1,000	1,000
Twist test C	Volts per mil	C-96/25/50	0.1285 and under	1,100	1,100	1,100
Flexibility (bend) (Conductor wound on mandrel after conditioning)	Max ratio of mandrel diam. to bare-condition diam. at which cracking of insulation may occur	C-96/25/50	0.1285-0.0907	1	1	1
		C-96/25/50	0.0808-0.0571	1	1	1
		C-96/25/50	0.0508-0.0320	1	1	1
		C-96/25/50	0.0285-0.0201	1	1	1
		C-96/25/50	0.0179-0.0113	1	1	1
		C-96/25/50	0.0100 and under	3	3	3
Flexibility (bend)	Max ratio of mandrel diam. to bare-condition diam. at which cracking of insulation may occur	E-168/125	All	3	3	3
		E-1/125	0.1285-0.0113	1	1	1
Before condition	Max ratio of mandrel diam. to bare-condition diam. at which cracking of insulation may occur	E-1/125	0.0100 and under	3	3	3
Continuity (1,000 ft)	Breaks	C-96/25/50	0.0179 and under	5	3	1
Effect of solvents (naphtha, toluol, sulfuric acid)	....	24 hr at 25 C	0.0159 and under	No appreciable swelling		
Abrasion resistance	Strokes	C-96/25/50	0.102-0.010	Average 30 and single test 15		
Adherence, 15 ft per sec.		C-96/25/50	0.102-0.0031	No cracks or loss of adherence		
Thermoplastic flow	Min °C	C-96/25/50	All	170	170	170

MAGNET WIRE, ROUND, COTTON-COVERED
Spec: JAN-W-583 Insulation Class A
Type C
Type C2

MAGNET WIRE, ROUND, GLASS-COVERED
Spec: JAN-W-583 Insulation Class B
Type GV
Type G2V

Requirement (all sizes)	Unit	Condition	Type			
			C	C2	GV	G2V
Dielectric strength	Volts per mil	C-96/25/50	100	100	125	125
Flexibility (bend)	Ratio	C-96/25/50	...	...	10	10
After	Ratio	E-5/200	...	...	20	20
Conditioning	Ratio	E-24/125	...	...	10	10

MAGNET WIRE, ROUND, GLASS-COVERED (SILICONE)
Spec: MIL-W-16072 (Ships) Insulation Class H
Type GH
Type G2H

Requirement	Unit	Condition	Nominal diam. bare wire	Type	
				GH	G2H
Dielectric strength	Volts per mil	C-96/25/0	All sizes	125	125
Layer to layer	(Min)	C-96/25/96	....	115	115
		E-200/250	....	125	125
Flexibility*	Ratio*	C-96/25/50	....	5	5
		E-200/250	....	5	5
Abrasion	Lb	E-200/250	0.064–0.040	2.0	4.0
			0.036–0.018	1.5	2.0
			0.016–0.007	0.6	1.0
Adherence, 15 ft per sec	....	C-96/25/50	0.102–0.003	No cracks outside point of failure	
Heat to failure	°C (min)		0.064–0.040	....	630
			0.036–0.018	....	700
			0.016–0.007		
Loss of weight	% (max)	E-500/250	0.064–0.007	0.2	0.2

* Flexibility (bending) requires a tapered mandrel for qualification tests, a tapered or straight mandrel for contract inspection tests. The conductor is wound on the mandrel after conditioning. Ratio is maximum ratio of mandrel diameter to bare-conductor diameter at which cracking of the insulation may occur.

Index

(Numbers refer to chapter-sections, not pages)